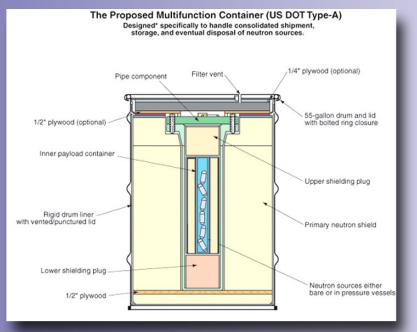
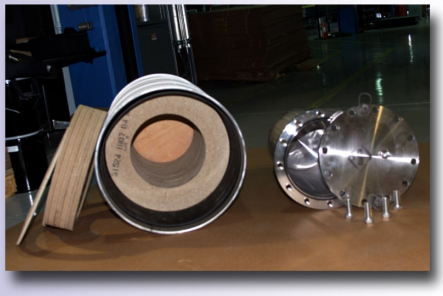
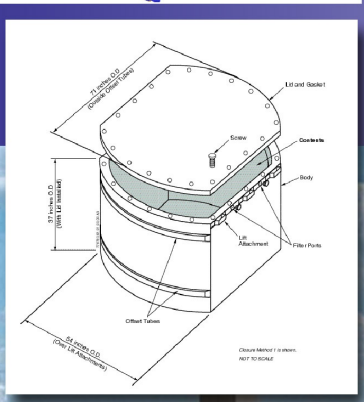
A Methodology for Disposition of DOE Neutron Sources

Report of the Neutron Source Trade Study Working Group

Nonactinide Isotopes and Sealed Sources Management Group







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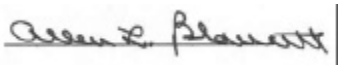
Allen Blancett	SRS/SRTC	Non-voting	
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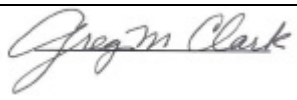
Greg Clark	RL	Voting	
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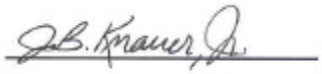
Joe Knauer, Jr.	ORNL/OR	Voting	
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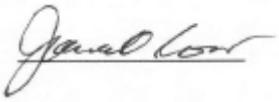
Jim Low	AL	Voting	
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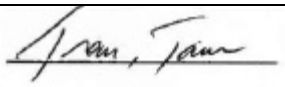
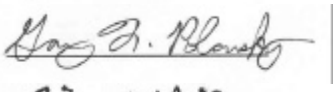
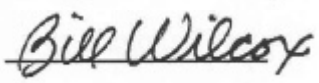
Tam Tran	SR	Voting	
Gary Polansky	SNL	Non-voting	
Bill Wilcox	LLNL	Non-voting	
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Acronyms

ANL	Argonne National Laboratory
DOE	Department of Energy
DOE/AL	Department of Energy/Albuquerque Operations Office
DOT	Department of Transportation
EM NM	Environmental Management Nuclear Materials
ES&H	Environmental Safety and Health
GTCC	Greater Than Class C
HIP	Heavy Isotopes Program
HLW	High Level Waste
INMM	Integrated Nuclear Materials Management
LANL	Los Alamos National Laboratory
LLW	Low-Level Waste
NEPA	National Environmental Policy Act
NISSMG	Nonactinide Isotopes and Sealed Sources Management Group
NMI	Nuclear Material Integration
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
OSRP	Offsite Source Recovery Project
RAMPAC	Radioactive Material Packaging
SARP	Safety Analysis Report for Packaging
SNM	Special Nuclear Material
SPAR	Special Performance Assessment Required
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TBD	To Be Determined
TRU	Transuranic
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

A Methodology for Disposition of DOE Neutron Sources
Report of the Neutron Source Trade Study Working Group

EXECUTIVE SUMMARY

Problem Statement

Define a methodology for use in selecting an appropriate disposition path for excess DOE neutron sources.

DOE sites hold a small, but significant number of neutron sources that are either excess or that may become excess in approximately the next fifteen years and for which guidance is needed for selecting an appropriate disposition path. Such neutron sources have already proven problematic in efforts to remove nuclear materials from closure sites such as Mound, Fernald, and Rocky Flats. The purpose of this study is to identify and evaluate credible alternatives for the disposition of DOE neutron sources.

An approximate inventory of neutron sources was developed for this study, which was sufficiently well-defined to establish a disposition path methodology and disposition options. This inventory includes nearly 1,200 items containing a total of more than 10,000 Ci. The inventory includes seven different radionuclides contained in a variety of sources.

The approach taken in this study was to establish a methodology for selecting appropriate disposition paths for these sources. First, existing reuse and disposal programs that might be or might become likely recipients of DOE neutron sources were identified. Acceptance criteria for these programs were researched and a sequential consideration of them was established, as shown in Figure ES-1. Sources not meeting the acceptance criteria of existing programs were identified as "Special Needs" material (i.e., sources above 28 Ci or non-defense TRU sources). A formal decision analysis was conducted for these sources to identify potential disposition alternatives.

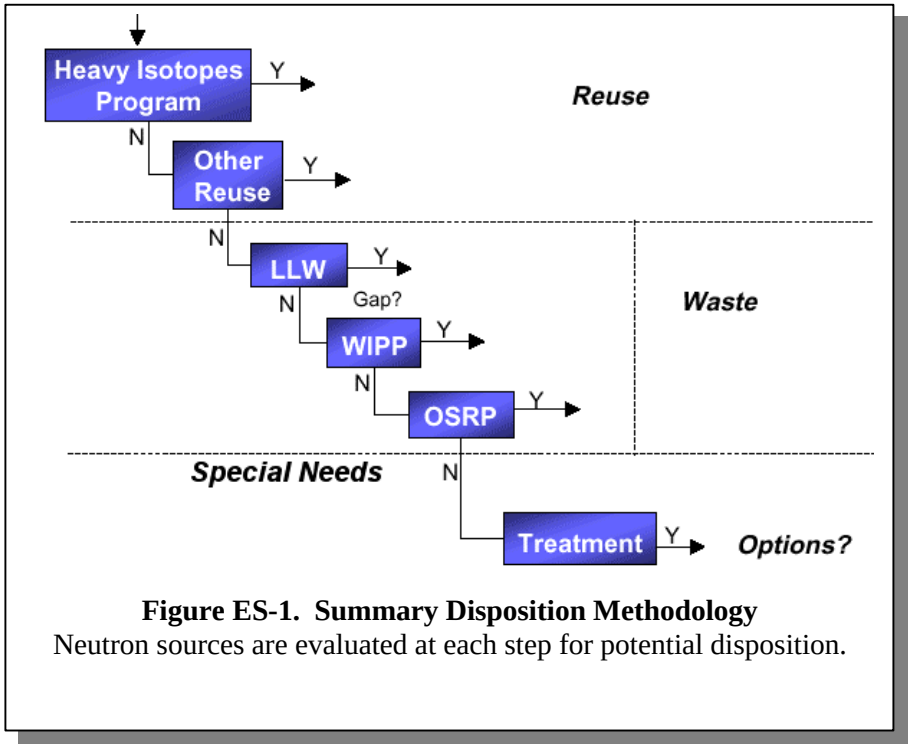


Figure ES-1. Summary Disposition Methodology
Neutron sources are evaluated at each step for potential disposition.

Four alternatives were defined for the analysis of disposition alternatives for these Special Need materials. These alternatives were evaluated against selected criteria representing the study goals, which included maximizing inventory disposition, technical feasibility, schedule compatibility, and minimizing cost. The decision methodology used a decision process identified in the Guidebook for Decision Support Methods.

Results of the scoring for the four alternatives by the decision analysis are shown below. Based on this evaluation, Direct Disposal is the preferred alternative for these materials.

Alternatives for Special Needs Material

Rank	Score	Alternative	Description
1st	68.8%	**Direct Disposal**	Direct disposal, as appropriate, as LLW, at WIPP, or long-term storage at sites (for non-defense TRU).
2nd	59.8%	**Distributed Storage**	Continued maintenance and storage in existing facilities, deferring permanent disposition decisions.
3rd	54.3%	**Consolidated Storage**	Transporting all excess sources to a single location for long-term storage and potential reuse or resolution of disposal issues.
4th	50.7%	**Processing for Disposal**	Chemical processing of source materials and blending into HLW streams for eventual geologic disposal.

The Neutron Source Trade Study, performed by subject matter experts across the complex, identified a methodology for use in recommending appropriate disposition paths for these sources. An evaluation of alternatives for their disposition identified a clear preference for reuse; if that was not possible, direct disposal of these materials was preferable over storage and processing alternatives. For sources without reuse potential, results of the decision analysis for special need sources indicate a strong preference for the Direct Disposal alternative, with somewhat lower preferences for two storage alternatives and Processing for Disposal was the least preferable alternative. The decision to select the Direct Disposal alternative resulted from an evaluation of the scoring with respect to the goals. A transportation container is needed eventually for each of the options, even if the sources are left where they are in distributed storage. For WIPP-bound sources, the Direct Disposal alternative can thus utilize transportation containers for disposal, while each of the other options adds an additional incremental cost.

Recommended Path Forward

Four recommendations are made as a result of this study:

1. **Reuse options for DOE neutron sources is recommended whenever possible. The resources of the Heavy Isotope Program and the NISSMG should be used in identifying reuse options for these materials.**
2. **Direct disposal is recommended as the disposition path for excess, non-reusable DOE neutron sources. A small quantity of material is currently excess and disposal of these items should be pursued. Larger items that are currently in programmatic use, and not suitable for recycle, should be planned for ultimate disposition through direct disposal.**
3. **Neutron sources that are non-defense TRU cannot be disposed at present and should be stored until a viable disposition path for DOE non-defense TRU is established.**
4. **The development of a Standard Waste Box as a container to both transport and dispose neutron sources should be pursued. It is recommended that DOE begin the process to design, certify, and license this container.**

A Methodology for Disposition of DOE Neutron Sources
Report of the Neutron Source Trade Study Working Group

1.0 Purpose

The purpose of this study is to identify and evaluate credible alternatives for the disposition of excess DOE neutron sources. Due to its importance to all of the disposition options, special consideration was given to transportation issues. The approach taken by the Neutron Source Working Group was to develop a methodology for use in selecting an appropriate disposition path for excess neutron sources. Finally, for those sources requiring additional evaluation, a decision analysis of four viable possibilities was used to select a preferred alternative.

2.0 Background

DOE sites hold a small, but significant number of neutron sources that are either excess to their needs or that may become excess in approximately the next fifteen years and for which guidance is needed for selecting an appropriate disposition path. Most of these neutron sources consist of an alpha-emitting radionuclide, such as americium-241, and a light element such as beryllium and are called "(α,n) sources." Some of the radioactive materials are Special Nuclear Material (SNM) and have special disposition and accounting issues. Another type of neutron source, often made with californium-252, relies on spontaneous fission for production of neutrons. The neutron source inventory used in this Trade Study was an update by the various sites of an earlier inventory obtained by the Nuclear Materials Integration (NMI) Project in 1997-1998 (See Appendix A). In an initial assessment [NISSMG, 1998], most sites indicated that their neutron sources would be disposed through the Radioactive Source Recovery Program (RSRP), described in Appendix B. When the RSRP ceased processing sources in 1999, these sites changed their baselines for neutron source disposition to "To Be Determined" (TBD). When this occurred, neutron sources constituted the single largest group of TBD disposition paths for nonactinide isotopes and sealed sources (NISS) materials in the DOE complex. These TBD disposition paths were especially problematic at DOE closure sites where removal of nuclear materials was on the critical path to other environmental management activities. Fortunately, at the Mound site, the Nonactinide Isotopes and Sealed Sources Management Group (NISSMG) was able to identify reuse options for the orphan sources remaining at this site. Recognizing that similar neutron sources with no defined disposition path existed at Fernald and Rocky Flats, as well as at other DOE sites across the complex, provided the impetus for this systematic evaluation of disposition options. This study supports the goals stated by EM-1 in improving safety performance, closing Rocky Flats, Fernald and Mound, consolidating nuclear materials out of EM sites or shrinking the EM footprint, and getting wastes to disposal facilities quickly by providing sites a methodology to determine the appropriate disposition path for this group of excess materials.

The Working Group for this Trade Study was established by the NISSMG[1] by memorandum dated April 27, 2001. The first meeting of the Working Group was held in Albuquerque on May 23-24, 2001. The most important result from that meeting was the decision to develop a methodology for selecting appropriate disposition options, depending on the characteristics of the neutron source, rather than simply defining a single or even a few preferred alternatives. A second meeting was held in Albuquerque on August 29-30, 2001. This meeting primarily concerned information collected by the Working Group needed to establish viable possibilities for handling sources that do not fit within existing

[1] NISSMG is an integral component of the DOE Environmental Management Nuclear Materials (EM NM) stewardship program.

programs. This included topics such as processing, transportation, and direct disposal. The Working Group Charter and a summary of attendance at these meetings are provided in Appendix. C.

3.0 Issues

The Working Group gathered information and raised a number of issues in the development and evaluation of disposition plans for these excess neutron sources. The key issues are summarized below and were used in defining the methodology for selecting disposition options for these materials. For sources without any current disposition options, referred to as "Special Needs" sources, consideration of these issues was important in defining and comparing disposition alternatives, which were evaluated in the decision analysis described in Section 5.0.

1. Site Capabilities: Disposition options, especially for the larger or more difficult sources, can depend on the materials handling and processing capabilities at a site. It is possible for a source to be unshippable and for a site to lack the capability to transform it into a form that can be shipped. The Offsite Source Recovery Project (OSRP) has made significant inroads on this problem by designing a "Special Form Capsule," into which non-conforming sources may be placed and shipped.

2. Disposal: Currently, most DOE sites are approved to ship low-level waste (LLW) to either the Nevada Test Site (NTS) or Hanford. A smaller number of DOE sites are approved to ship transuranic waste (TRU) to the Waste Isolation Pilot Plant (WIPP), which is limited to accepting only defense-related TRU. The timing of shipments to WIPP may also be an issue for some sites. The interpretation of the meaning of "defense-related" is discussed in a 1996 memorandum [Nordhaus, 1996], which concludes that WIPP is permitted

   > "…to dispose of defense TRU waste resulting from all of the noncivilian activities and programs of DOE, including weapons production, naval reactors, defense research and development, associated defense environmental restoration and waste management, and other defense-related activities…"

   This definition excludes wastes from DOE's civilian atomic energy activities and programs. Therefore, there are currently no disposal options available for non-defense TRU wastes.

3. Transportation: The radiation emitted by neutron sources is not effectively shielded by the shielding used in most transportation packaging. Consequently, options for their shipment using existing licensed packages are limited, particularly for a number of neutron sources, because of their unusual isotopic composition, high activity, and large dimensions.

4. Source Variety and Variability: Neutron sources commonly employ four different actinides, two non-actinide radioisotopes, and four different light elements. They range in activity from hundreds of curies to millionths of curies or less. This variability complicates transportation and processing considerations.

3.1 Neutron Source Inventories

An inventory of source holdings within the DOE complex was completed as a part of the NMI Project in the 1997-1998 time frame. As part of this Trade Study, sites with significant neutron source holdings were asked to update their inventories. Most sites were able to provide a partially updated inventory used to establish qualitatively the number of sources that might be eligible for various disposition alternatives. The result in many cases is considered qualitative, because data critical to disposition evaluations were not included in the database. For example, a history of prior use in defense programs is required for WIPP disposal, but that information previously had not been included in the database. Many sites were able to provide a preliminary determination of prior defense-related use and this information is now included in the database.

Figures 3-1 and 3-2 provide a graphical representation of the isotopic fractions of the items and activity, respectively. Figure 3-1 shows that ^{241}Am and ^{252}Cf account for a large majority of the total inventory, while Figure 3-2 indicates the large dominant contribution of ^{238}Pu to the overall activity. Figures 3-3 and 3-4 similarly show the relative fractions of small (<28 Ci) and large (>28 Ci) items and activity. Figure 3-3 indicates that 95% of the items in the inventory are items that individually contain less than 28 Ci, and Figure 3-4 that the total activity is dominated by the few items that individually contain more than 28 Ci. An overview of initial neutron source inventories is shown in Table 3-1. In the table, sources are grouped by curie content greater than or less than 28 curies, which is the upper limit for which the OSRP S100 transportation package is licensed. The S100 is a DOT Type A packaging that was recently licensed to transport neutron sources, but it is undergoing manufacturing changes, so fabrication and use has been delayed pending approval of Rev. 21 of the TRUPACT II SAR. It is similar to the pipe overpack with neutron shielding material added. Table 3-2 shows the distribution of the inventory in these two categories at various sites across the DOE complex. A more detailed report on the source update process and resulting inventories is given in Appendix A. A major uncertainty continues to be defense history. It is known that the inventory information used in this study does not represent a complete list of DOE sources in the complex; however, the intent of this study is to establish general disposition alternatives that can be applied as other materials are identified. It should be noted that many of the sources have not yet been declared surplus.

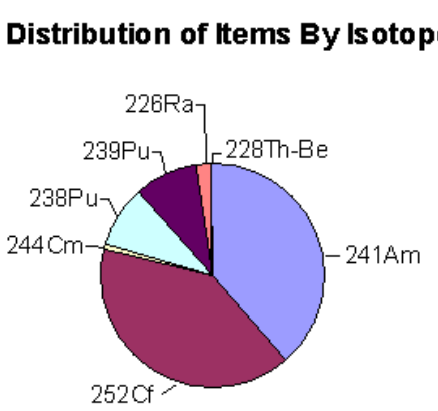


Figure 3-1. Isotopic Distribution Among Items

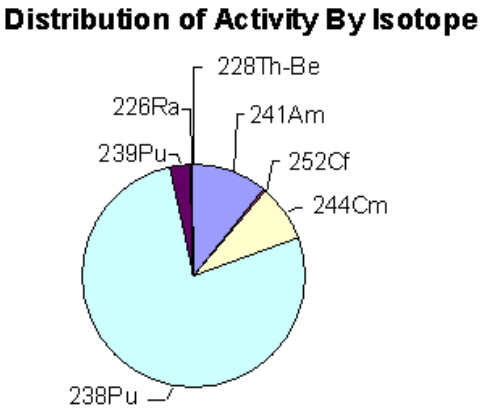


Figure 3-2 Isotopic Distribution of Activity

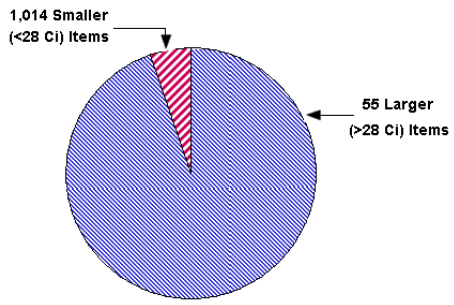


Figure 3-3. Distribution of Smaller vs. Larger Items.

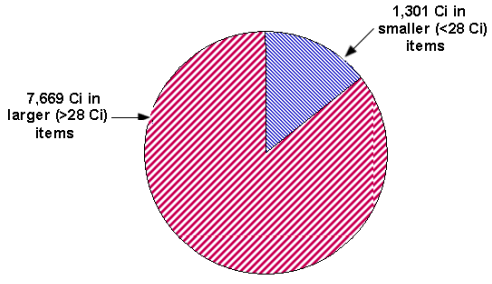


Figure 3-4. Distribution of Activity Between Smaller and Larger Items.

Table 3-1. Neutron Source Inventories by Material and Size*

Material	<28		>28		Total	
	Items	Curies	Items	Curies	Items	Curies
^{241}Am-B	2	4	0	0	2	4
^{241}Am-Be	275	296	1	50	276	346
^{241}Am-Be mix	2	0	0	0	2	0
^{241}Am-F	4	4	0	0	4	4
^{241}Am-Li	126	351	3	300	129	651
Total ^{241}Am	**409**	**656**	**4**	**350**	**413**	**1,006**
Total ^{252}Cf	**427**	**47**	**0**	**0**	**427**	**47**
^{244}Cm-Be	1	11	0	0	1	11
^{244}Cm-O	0	0	7	700	7	700
Total ^{244}Cm	**1**	**11**	**7**	**700**	**8**	**711**
^{238}Pu-B	2	25	0	0	2	25
^{238}Pu-Be	37	222	41	6,383	78	6,604
^{238}Pu-F	2	25	0	0	2	25
^{238}Pu-Li	12	77	2	179	14	256
Total ^{238}Pu	**53**	**349**	**43**	**6,562**	**96**	**6,911**
^{239}Pu-Be	74	172	1	57	75	230
^{239}Pu-Be mix	4	17	0	0	4	17
^{239}Pu-F	1	7	0	0	1	7
^{239}Pu-O	22	28	0	0	22	28
Total ^{239}Pu	**101**	**223**	**1**	**57**	**102**	**281**
^{226}Ra-B	2	3	0	0	2	3
^{226}Ra-Be	20	11	0	0	20	11
Total ^{226}Ra	**22**	**14**	**0**	**0**	**22**	**14**
Total ^{228}Th-Be	**1**	**0**	**0**	**0**	**1**	**0**
Totals	**1,014**	**1,301**	**55**	**7,669**	**1,069**	**8,970**

* Activities rounded to nearest curie.

Table 3-2. Inventory Distribution by Site*

Site Name	<28		>28		Total	
	Items	Curies	Items	Curies	Items	Curies
Sandia National Lab - Albuquerque	82	49	0	0	82	49
Los Alamos National Lab	242	276	3	219	245	494
Grand Junction	6	4	0	0	6	4
Pantex	22	46	0	0	22	46
Princeton Plasma Physics Lab	3	0	0	0	3	0
Environmental Measurements Lab	5	0	0	0	5	0
Fermi National Accelerator Lab	7	38	0	0	7	38
Argonne National Lab - East	49	98	3	313	52	411
Argonne National Lab - West	19	90	0	0	19	90
Brookhaven National Lab	58	74	19	722	77	796
Savannah River	113	88	4	554	117	643
University Sites (ORAU)	1	7	0	0	1	7
Portsmouth Gaseous Diffusion Plant	1	0	0	0	1	0
Oak Ridge ETTP (K-25)	6	12	0	0	6	12
Oak Ridge Y-12 Plant	34	76	0	0	34	76
Oak Ridge National Lab	90	118	0	0	90	118
Fernald	2	0	0	0	2	0
Hanford	14	23	0	0	14	23
Pacific Northwest National Lab	46	77	7	700	53	777
INEEL (including ICPP)	69	67	0	0	69	67
Knolls Atomic Power Lab	2	0	0	0	2	0
Vallecitos Nuclear Center	1	0	0	0	1	0
Stanford Linear Accelerator Center	1	0	0	0	1	0
Lawrence Berkeley National Lab	35	60	2	116	37	176
Lawrence Livermore National Lab	28	34	3	290	31	324
Nevada Test Site	74	65	2	110	76	175
Bettis Atomic Power Lab	0	0	12	4,644	12	4,644
Foreign Sites	1	0	0	0	1	0
University Sites	2	0	0	0	2	0
National Inst. of Standards & Technology	1	0	0	0	1	0
TOTALS	**1,014**	**1,301**	**55**	**7,669**	**1,069**	**8,970**

* Activities rounded to nearest curie.

3.2 Reuse Considerations

The Heavy Isotope Program (HIP) accepts all but the smallest ^{252}Cf sources (See Appendix D). For ^{252}Cf sources not accepted by HIP, either commercial reuse or LLW disposition paths exist.

Commercial reuse options exist for ^{241}Am/Be sources in the range of 5 to 10 Ci, if they have the desired pedigree, manufacturer(s), and history. These sources can be processed commercially to fabricate larger, marketable sources. Sources that are in the range of 20 Ci may be available for direct commercial reuse, again depending upon their pedigree.

Neutron sources containing ^{243}Am, ^{244}Cm, or higher atomic masses are generally rare and frequently have reuse potential in the HIP or other programs, e.g., for transmutation or accelerator projects. Larger ^{238}Pu sources have had reuse potential in research and development work. Removal of beryllium to the levels required for manned space applications, however, might preclude reuse in that area.

The NISSMG works to find reuse options for other excess materials. NISSMG is implementing a Virtual Source Bank to facilitate reuse by making excess DOE sealed source information available through the Internet. The NISSMG is developing this tool to assist in determining if an available source matches user needs, when an "old" source is available, the need to procure a "new" source thus can be avoided – a waste minimization concept. The Virtual Source Bank and contact information is accessible from a link on the NISSMG web page: http://emi-web.inel.gov/nissmg/index.htm.

3.3 Disposal Considerations

Most DOE sites are approved to ship LLW to either the NTS or Hanford. The NTS and Hanford will accept LLW for disposal if it is below 100 nCi/g and meets the site's Waste Acceptance Criteria (WAC) (See Appendix E.).

A smaller number of DOE sites are approved to ship to WIPP. WIPP accepts defense TRU waste provided the items can be shipped and meet the WIPP WAC (See Appendix F.). WIPP does not accept non-defense TRU waste. Therefore, there are currently no disposal options available for non-defense TRU wastes.

Scheduling considerations at WIPP imply acceptable neutron sources will require longer-term storage before out-year disposal. OSRP accepts (if Greater-Than-Class C [GTCC]) commercial and on a case-by-case basis DOE, ^{238}Pu, ^{239}Pu, and ^{241}Am neutron sources (See Appendix G). Security considerations, however, severely limit acceptance of ^{239}Pu.

3.4 Transportation Considerations

The fundamental issues in transporting neutron sources are:

1. sources are sufficiently large in terms of radioactive content and/or neutron emission rate that they exceed the capability of existing transportation packages,
2. transportation package approved contents lists do not include the materials used in neutron sources, and
3. some sources may have dimensional constraints that prevent them from fitting into existing packagings.

For ^{252}Cf sources, the HIP identified a variety of Type A and B shipping containers they use to ship and return ^{252}Cf neutron sources to and from ORNL (See Appendix H.) These packagings range from a six pound, 5-gallon drum with a limit of less than 1 μg to the Cannonball (Type B/USA/5740B( )) and the Snowball (Type B/USA/6642/B( )) that can transport up to 0.06 and 0.08 grams, respectively. General

information for each shipping container, including overall dimensions, weight, and ^{252}Cf shipping capacity are provided in Appendix H.

The OSRP has developed a Type A packaging system, the S100, which can be used to both transport and directly dispose of neutron sources at WIPP. The S100 was approved in Rev. 19 of the TRUPACT II Safety Analysis Report [DOE, 2001a] in CY2001. The S100 is currently undergoing changes in manufacturing technologies, which will be incorporated in Rev. 21 of the TRUPACT II Safety Analysis Report in CY2002. When transported in the TRUPACT-II, a Type B packaging, the S100 is capable of transporting neutron sources as large as 28 Ci. Currently, the isotopes are limited to ^{238}Pu/Be, ^{239}Pu/Be, and ^{241}Am/Be. Of the known DOE inventory, 95% of the items contain less than 28 Ci and could be shipped in this manner or in other Type A packagings authorized for neutron sources. In the S100, it is possible that a loading in which only one drum had a neutron source could accommodate a source as large as 45 Ci. The limiting factor would likely be the 200 mrem/hr surface dose limit applicable to contact-handled waste. Also, there is a possibility that neutron sources as large as 54 Ci could be placed in a "Special Form" capsule that OSRP has developed and shipped in the S100. Thus, there appear to be three general groupings of neutron sources:

- sources smaller than 28 Ci, which can be shipped in the S100 or other DOT Type A packages;
- sources between 28 and 60 Ci, for which some combination of "Exclusive Use" shipments, special loadings (such as only one drum containing a source), and use of a Special Form capsule might be enough to allow shipment; and
- sources larger than about 60 Ci, which have few, if any, licensed packagings for shipment at this time.

For neutron sources exceeding DOT Type A limits, a Type B packaging is required. Type A limits for relevant isotopes are shown in Table 3-3.

Table 3-3. DOT Type A Limits for Relevant Isotopes (Source: 49 CFR 173.435)

Radionuclide	A_1 (Ci)	A_2 (Ci)
Am-241	54.1	5.41E-3
Cf-252	2.70	2.70E-2
Cm-244	108	1.08E-2
Pu-238	54.1	5.41E-3
Pu-239	54.1	5.41E-3
Ra-226	8.11	0.541
Th-228	8.11	1.08E-2

A_1 = the maximum activity of special form radioactive material permitted in a Type A package.

A_2 = the maximum activity of radioactive material, other than special form, Low Specific Activity or Surface Contaminated Object, permitted in a Type A package.

DOE's RAMPAC (Radioactive Material Packaging) Database website was queried to identify certified packages that might be used to transport the larger neutron sources. Also, the NUREG, "Directory of Certificates of Compliance for Radioactive Materials Packages," [NUREG, 2000] and other resources were consulted to identify currently licensed packagings that list neutron sources in their authorized contents (See Appendix I.) Some packagings that have been available to transport neutron sources in the past are no longer certified, e.g., the 9968. Each Certificate of Compliance for a certified packaging has an authorized contents section, which designates the isotopes that may be transported in that packaging. The larger activity neutron sources identified include: ^{238}Pu/Be, ^{238}Pu/Li, ^{238}Pu/F, ^{239}Pu/Be, ^{241}Am/Be, and ^{241}Am/Li. For ^{239}Pu/Be and ^{241}Am/Be, the only packaging identified is the S100

in the TRUPACT-II (TRUPACT-II is the certified Type B packaging with the Type A S100 inside.) with a limit of 28 Ci. A United Kingdom packaging was identified that could handle 30 Ci, but it is for U.S. import and export only, and it has only a slightly higher activity limit than the S100. For ^{238}Pu/Be special form sources, the S5W Refueling Source cask was identified as allowing up to three ^{238}Pu/Be sources of not more than 925 Ci total. No Type B packagings were identified that had authorized contents listing ^{238}Pu/Li, ^{238}Pu/F, or ^{241}Am/Li for activities greater than 15 Ci. Several spent fuel casks were tentatively identified that list neutron sources in their authorized contents. Some of these were for specific reactors, e.g., Dresden Unit 1 and FSV-1 Unit 3 (Fort St. Vrain). Others listed simply neutron source components or neutron sources meeting special form with a U-235 equivalent limit. For these, a specific evaluation against the cask Safety Analysis Report would be required to determine if the larger neutron sources could be shipped in any given spent fuel cask. Some of these casks have limited availability and may not be in a given site's authorization basis for use.

The RAMPAC query and C of C search was limited to isotopes and activity, and did not evaluate the physical dimensions of the sources versus the packagings.

The remaining 5% (~61) of the source items contain more than 28 curies each and may not be suitable for transportation in any currently licensed package. Since few transportation packagings included neutron sources in their approved contents, it may be necessary to seek revision of their Certificates of Compliance and/or design, build, and certify new transportation packagings. In order to use any disposition option other than continued storage at their present site, a transportation packaging must be available or developed. The ability to transport the neutron sources is key to direct disposal, consolidation, or off-site processing options. For very large sources, there are two packaging alternatives into which enough shielding material might be placed to achieve acceptable dose rates. The first of these is the 100 gallon drum. If it were filled with the same shielding material as is used in the S100, it could accommodate neutron sources packaged in the S100 as large as about 100 Ci. (Supporting shielding calculations are described in Appendix J.) If a similar approach were taken with a "Standard Waste Box," neutron sources possibly as large as 1,000 Ci might be accommodated. Use of a Standard Waste Box provided with additional shielding could be used to transport all of the sources identified in the inventory. In addition, for defense TRU neutron sources, the Standard Waste Box can then be used for direct disposal at WIPP without repackaging. This discussion assumes that dimensions of the sources are compatible with the packaging.

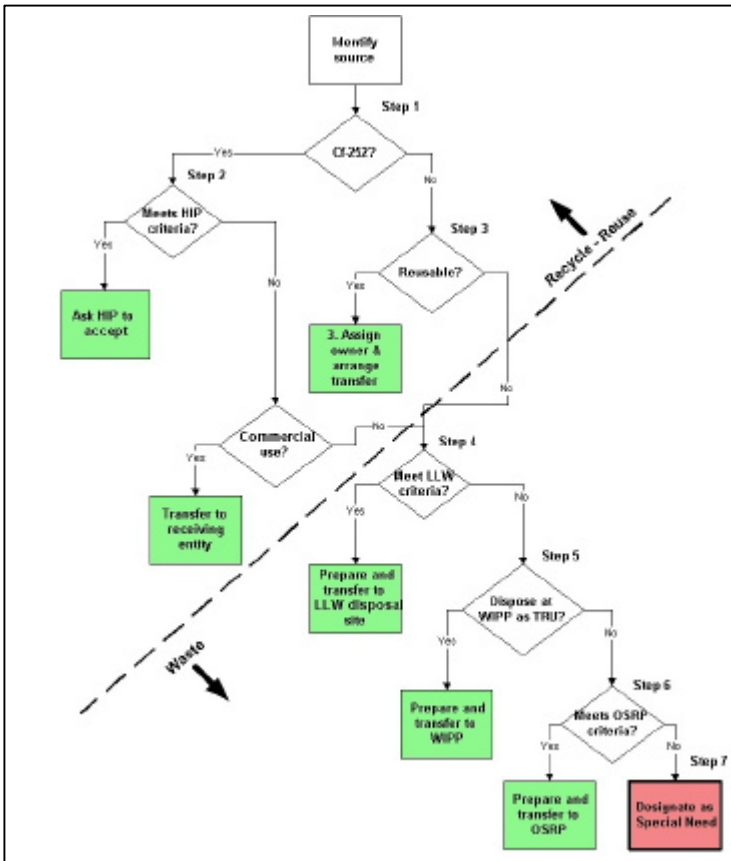


Figure 4-1. Disposition Methodology Flowchart
This flowchart represents the consensus determination of the Working Group of preferred disposition paths for different neutron source types.

4.0 Disposition Methodology

A methodology for selecting an appropriate disposition alternative was developed based upon characteristics of the sources. The methodology first considers options for productive use of the sources or the materials they contain. Then it considers various disposal options, including disposal as LLW, disposal at WIPP, and assignment to the OSRP. Sources that cannot meet the acceptance criteria for reuse or disposal must be considered on a case-by-case basis. For these latter "Special Needs" sources, a decision analysis was performed as described in Section 5.0 to evaluate alternatives for their disposition.

The steps in the methodology are illustrated in Figure 4-1 and described below.

Step 1. HIP Acceptance of ^{252}Cf Sources *(All Sources)*
If the source radionuclide is not ^{252}Cf, go to Step 3. If the ^{252}Cf source meets the criteria for the Heavy Isotopes Program (HIP), HIP is asked to accept it; otherwise, go to Step 2. HIP acceptance criteria (See Appendix D.) require that the source was fabricated at ORNL or SRS for government, university, or not-for-profit industrial/commercial use. Other sources may be acceptable with special permission.

Step 2. Commercial Use of ^{252}Cf Sources *(^{252}Cf sources not acceptable to HIP)*
If the source material can be used commercially, transfer to a receiving entity; otherwise go to Step 4. NISSMG coordinates and promotes reuse by communicating with source owners and potential users, and through operation of the internet-based "Virtual Source Bank" to identify sources available for reuse.

Step 3. Reuse of Non-^{252}Cf Sources *(Non-^{252}Cf Sources)*
If the source or source material is reusable, transfer to the new owner. Contact NISSMG to identify reuse opportunities, using the Virtual Source Bank.

Step 4. LLW Disposal *(Non-reusable Sources)*
If the source meets LLW disposal criteria, prepare and transfer for disposal at Hanford, NTS, or a commercial LLW site; otherwise go to Step 5. See Appendix E for a more complete description.

Step 5. WIPP Disposal *(Non-reusable sources exceeding LLW criteria)*
If the source meets WIPP's TRU waste disposal criteria, prepare and transfer for disposal at WIPP, otherwise continue on to Step 6. See Appendix F for details.

Step 6. Transfer to OSRP *(Non-reusable sources exceeding LLW and WIPP criteria)*
If the source meets the criteria for acceptance by the OSRP, prepare and transfer to OSRP; otherwise go to Step 7. See Appendix G for details.

Step 7. Special Need Sources *(Non-reusable sources exceeding LLW, WIPP, and OSRP criteria)*
If the source cannot meet any of the foregoing criteria, it is designated "Special Needs" and may require resolution of two primary issues: 1) the ability to transport the source away from the owning site, and 2) the ability to transform the source into a form acceptable for disposal or reuse.

Three types of neutron sources that would fall into the "Special Needs" category were not included in the following decision analysis. These are: ^{244}Cm, ^{226}Ra, and ^{228}Th. For these three isotopes, it is possible to evaluate them under another ongoing NISSMG trade study - the SPAR (Special Performance Assessment Required). The purpose of the SPAR trade study is to develop and document a methodology to demonstrate that some DOE surplus materials can be safely disposed as low-level radioactive waste on a case-by-case basis, even though the material characteristics may exceed select requirements of a disposal site's waste acceptance criteria. (NISSMG, 2001) For non-defense TRU neutron sources, sites should examine opportunities to co-dispose of these materials as HLW.

A preliminary effort at allocating the inventory among these disposition options, based only on source material, activity, and defense-related history, is provided in Table 4-1 (See Appendix A). In many cases, the sites have not yet determined the defense-related history of the specific neutron sources, so those are labeled as "unknown," with "Possible WIPP," "WIPP?", or "OSRP?" in Table 4-1. The numbers of neutron sources in each category are presented in terms of <28 Ci and >28 Ci to give an indication of where there may be transportation issues.

Table 4-1 Approximate Disposition Categories, Based on Size and Defense History

Disposition Criteria	Re-Use	LLW <5 mCi	WIPP Defense <28 Ci	Possible WIPP Unknown <28 Ci	WIPP or OSRP Defense >28 Ci	WIPP? or OSRP? Unknown >28 Ci	N-D TRU Shippable NonDef <28 Ci	N-D TRU Non-Ship NonDef >28 Ci
^{241}Am	?	8 11µCi	49 48 Ci	311 561 Ci		4 350 Ci	82 80 Ci	
^{252}Cf	254 92.6 Ci	179 182 µCi						
^{244}Cm	?			50 547 Ci		5 235 Ci		
^{238}Pu	?	1 <1 µCi	23 146 Ci	26 195 Ci	36 6254 Ci	20 846 Ci	4 54 Ci	2 348 Ci
^{239}Pu		2 2 µCi	35 59 Ci	49 121 Ci		1 57 Ci	22 41 Ci	1 52 Ci
^{226}Ra		22 14 Ci						
^{228}Th		1 --						

5.0 Decision Analysis for "Special Needs" Sources

As part of this work, a programmatic decision analysis was performed to evaluate several alternatives for dispositioning Special Need items for which none of the disposition paths described above are currently appropriate or feasible. Those sources remaining at Step 7 of the methodology include non-defense TRU sources (and defense-related, non-TRU sources) that cannot be accepted at WIPP and for which there are no reuse options, have too large an activity to be disposed of as LLW, or are unacceptable to OSRP. In effect, this includes the small fraction (~5%) of sources in the inventory having an activity greater than 28 curies. The decision analysis is described in detail in Appendix K. Sensitivity of the results of the decision analysis is described in Appendix L.

The decision method, selection of evaluation criteria, and the scoring method used in this trade study are based on standards sources of decision methodologies, including A *Guidebook for Decision Support Methods* [DOE, 2001b]. An application of these standard methodologies (See Figure 5-1) was developed to support the implementation of decision analysis methods for the Integrated Nuclear Materials Management (INMM) Program.

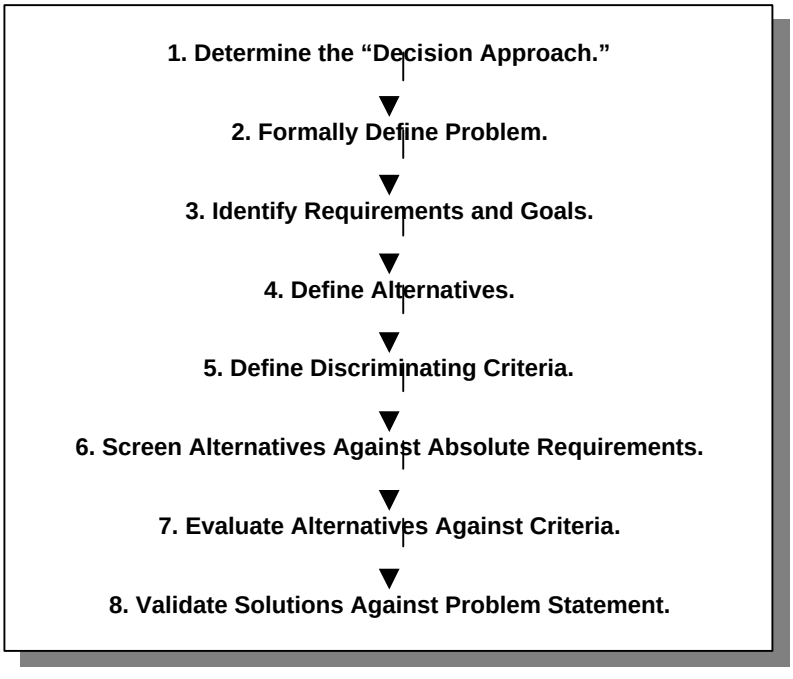


Figure 5-1. Decision Analysis Methodology Steps.

Problem Statement:

Identify permanent disposition paths for excess DOE neutron sources having no clear disposition path and qualitatively evaluate if there is a significant preference among alternative disposition paths for these sources.

Requirements and Goals:

No formal regulatory or DOE requirements or specific drivers apply to this evaluation. Five goals were established for this study to allow discrimination between alternatives: 1) maximize the disposition of material, 2) maximize use of technically feasible processes, 3) minimize ES&H impacts, 4) minimize cost, and 5) maximize schedule compatibility.

Alternatives Development:

The neutron source disposition methodology (Section 4.0.) presents reuse and disposal options for a number of neutron sources. Those items that end up in Step 7 of the methodology are designated as "Special Needs" material and require additional analysis prior to disposition. Four alternatives were identified for evaluation: 1) distributed storage, 2) consolidated storage, 3) processing for disposal, and 4) direct disposal.

The analysis is limited to the small fraction of sources in the inventory containing activities greater than 28 curies, and non-defense TRU sources. This assumes that the remaining sources can be dispositioned through reuse, disposal as LLW, or as TRU waste at WIPP.

1. Distributed Storage (Baseline)

This alternative assumes continued maintenance and storage of these sources and defers permanent disposition decisions. This alternative does not address concerns related to processing, reuse, transportation, or disposal. This alternative represents the current baseline situation and is included for comparison in the decision analysis against other potential disposition alternatives.

2. Consolidated Storage

This alternative transports all excess sources to a single consolidation location for long-term storage, pending resolution of disposal issues or potential reuse. Transportation to the selected consolidated storage site and storage considerations apply to this alternative. An advantage of this alternative over distributed storage is that it may minimize infrastructure costs, facilitate future shipments, and reduce the EM footprint in line with new EM-1 goals. What happens to the material after receipt by the selected consolidated storage site (long-term storage, reuse, disposal) is not treated by the decision analysis.

3. Processing for Disposal

For most of the small fraction of >28 Ci sources that are not "defense-related" and cannot be disposed of as TRU waste at WIPP, chemical processing provides a disposal solution. The radionuclides are mixed into HLW streams for eventual disposal at a deep geologic repository. A small number of these non-defense sources may not be suitable for such processing, but are a negligible fraction of the complex's overall non-defense inventory. Processing for disposal resolves a key issue for non-defense TRU material. The neutron sources would be transported to a single processing facility at Argonne National Laboratory-West (ANL-W) or the Savannah River Technology Center (SRTC); the specific facility would be selected after a more detailed review of capabilities and infrastructure upgrades required. Under this alternative, the material is separated and processed into HLW, which would ultimately be disposed of at a HLW repository. Note that this alternative involves the need to transport the sources to a processing facility. Unfortunately, transportation containers may not be available for this purpose. The problem of the lack of available transportation packaging also applies to the consolidated storage and direct disposal alternatives.

Two separate processing options were considered in defining this alternative. One option is the development of an electrometallurgical process at ANL-W. This option, described in more detail in Appendix M, uses the Hot Fuel Dissolution Apparatus (HFDA) in the Hot Fuel Examination Facility (HFEF) to convert PuO_2/Be sources into two waste streams, with the PuO_2 converted to $PuCl_3$ in a ceramic waste form, and the Be converted into a Be/U product through an electrorefining process. Some additional equipment would be needed to prepare the sources for processing, and there is some uncertainty in the process methodology. No additional shielding is anticipated as necessary and incremental waste would not be generated by this process.

The second option (described in more detail in Appendix N) is a chemical or physical separation and repackaging process in the High-Level Cells (HLC) facility at the SRTC. Additional shielding is needed for the processing facility, and there is some minor uncertainty in the chemical processing option. No NEPA modifications are considered likely.

These processes were developed for treatment of the larger (>28 Ci) sources and assume the smaller sources would be disposed of through other defined disposition paths. Cost and schedule estimates for these processes range from $750K to $2.48M with an operational period of 2-4 years. Either option could account for most, and perhaps all, of the ^{238}Pu and ^{241}Am sources. Post-processing considerations such as waste packaging, transportation, and disposal or reuse are not included in the decision analysis for this alternative.

4. Direct Disposal

The fourth alternative recognizes that the long-term solution for all of these excess neutron sources is disposal. Possible disposal options include LLW disposal for some sources or disposal as TRU at WIPP. Direct disposal involves packaging and shipping the inventory to the disposal site and ensuring satisfaction of the waste acceptance criteria for the disposal site.

This alternative assumes licensing of the Standard Waste Box with additional neutron shielding for transporting these sources and a disposition path only for defense-related TRU waste acceptable at WIPP (i.e., there is no disposition path for “non-defense” items, in particular, those that can’t be disposed of as LLW).

Discriminating Criteria:

Criteria were developed for use in discriminating among alternatives their ability to meet the established goals. The discriminating criteria defined for this study include:

1. Dispositioned Inventory
2. Complexity
3. Flexibility
4. Transportation Availability
5. Dose Potential
6. Facility Cost
7. Processing Cost
8. Schedule Compatibility

A more detailed definition and description of the criteria is provided in the discussion in Appendix K. The five goals were first qualitatively weighted by their perceived importance to the decision. By consensus of the expert decision team, it was determined that the goal of maximizing the disposition of the inventory was of greatest importance, followed closely in importance by the goals of technical feasibility and schedule compatibility.

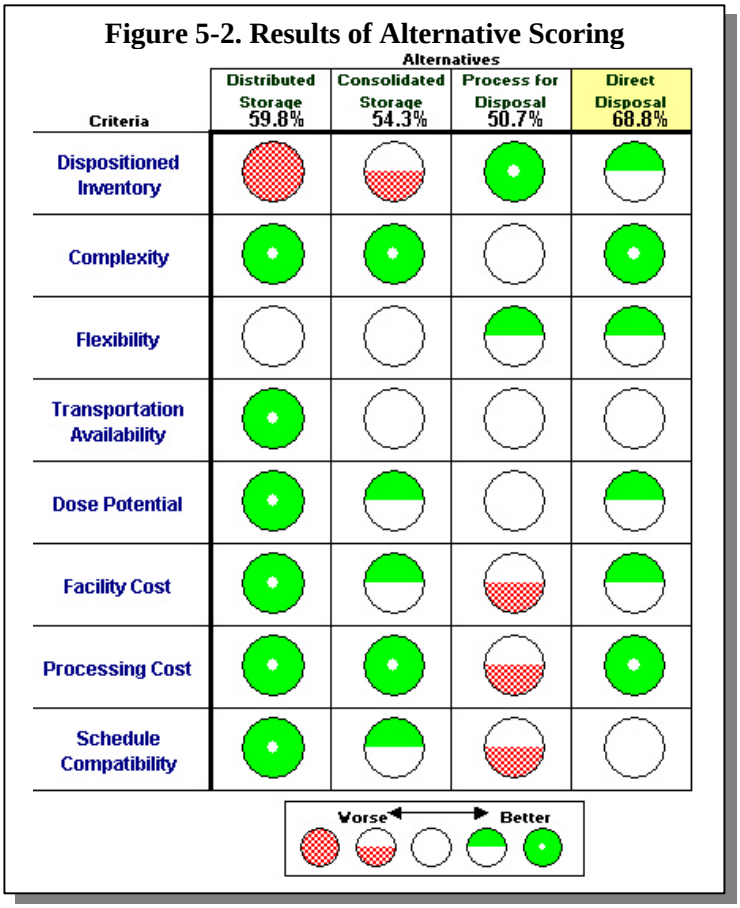
The eight criteria were then allocated among the five defined goals. For the two goals assigned more than one discriminating criteria, the criteria were then weighted by their perceived importance relative to that goal.

Scoring and Results

For each alternative, a score was assigned to each of the criteria by the decision team, using a scoring range of 1 (worst/bad) to 10 (best/good), although use of the full range for any criterion was not required (see Appendix K, Table K-2).

The scores (averaged over individual scores assigned by each of the several members of the decision team) are shown in Appendix K, Table K-2, and in the schematic "Consumer Reports" chart of Figure 5-2.

Figure 5-2. Results of Alternative Scoring



Ranked Alternatives

Rank	Alternative	Score
1st	Direct Disposal	68.8%
2nd	Distributed Storage	59.8%
3rd	Consolidated Storage	54.3%
4th	Process for Disposal	50.7%

Results indicated a clear preference for the Direct Disposal alternative. Somewhat less preferable were the Distributed Storage and Consolidated Storage alternatives. Least preferable was the Process for Disposal alternative.

Direct Disposal was identified as the alternative that could provide final disposition for nearly the entire inventory. Only the non-defense related neutron sources (a minor component of the non-defense inventory across the complex) would be excluded. This alternative shares similar transportation and packaging issues with the less preferable Consolidated Storage alternative, achieves disposition for a larger fraction of the inventory than the Distributed Storage alternative, and shares similar cost and safety considerations with both of these alternatives. The Process for Disposal alternative scored lower in most areas, but does have the ability to process the entire inventory by combining the material with a HLW stream for eventual disposal at a HLW repository.

Advantages and disadvantages of the four alternatives were reviewed during the scoring discussions and are summarized below. The three alternatives of Consolidated Storage, Processing for

Disposal, and Direct Disposal are all subject to the major disadvantage that there is currently no packaging licensed for the transportation of these sources. These sources require specific shielding for neutrons, which is not available in most licensed packagings, and dimensions of some of these sources prevent their being contained in those packagings. Resolution of these issues is needed before these materials could be transported to a consolidated storage location, a processing facility, or a disposal site. Since a suitable packaging is needed to transport the neutron sources, it can also be designed for direct disposal.

The current baseline system of storing excess neutron sources at various sites is the only alternative that does not involve the transportation and disposal issues of the other three alternatives. The major disadvantage of the Distributed Storage alternative, however, is that it does not result in final disposition for any of the sources.

The chief advantage of the Consolidated Storage alternative, assuming transportation issues can be resolved, is that it involves well-proven systems, no significant additional cost, and, by removing excess sources from various sites, potentially allows closure of other storage facilities. A disadvantage of this alternative is that long-term storage does not result in disposal as a final disposition, therefore implying long-term ongoing costs.

The Processing for Disposal alternative has a significant advantage over the other alternatives in overcoming disposal issues by virtue of its transforming the material into high-level waste, for which disposition in a HLW repository is a defined disposition path. Disadvantages include greater complexity, cost, schedule, and safety considerations, as well as the packaging and transportation issue.

Direct Disposal was identified by the decision analysis as the most preferable disposition path of the four alternatives, which is not an overly surprising conclusion. Assuming resolution of the packaging and transportation issues common to three of the alternatives, it results in the final disposition of the majority of the sources, and if a solution is found to permit disposal of the non-defense TRU component, for the entire inventory.

6.0 Conclusions

A methodology was defined, based upon source characteristics and emphasizing potential reuse options, which is useful for identifying appropriate disposition options for many of the excess neutron sources in the DOE complex. For the small fraction of “Special Need” sources for which no acceptable disposition alternative exists, a decision analysis indicated that direct disposal is a preferred alternative over storage or chemical processing alternatives.

Although direct disposal was the preferred alternative for the disposition of these Special Need sources, several actions are needed for this to become a realistic disposition option. Most prominent is the need to establish a disposal solution for high-activity neutron sources that do not meet the acceptance criteria at WIPP. In addition, further effort is encouraged to design and certify/license transportation packages suitable for both transporting and disposal of these sources.

7.0 Recommendations

Four recommendations are made as a result of this study:

1. Reuse options for DOE neutron sources is recommended whenever possible. The resources of the Heavy Isotope Program and the NISSMG should be used in identifying reuse options for these materials.
2. Direct disposal is recommended as the disposition path for excess, non-reusable DOE neutron sources. A small quantity of material is currently excess and disposal of these items should be pursued. Larger items that are currently in programmatic use, and not suitable for recycle, should be planned for ultimate disposition through direct disposal.
3. Neutron sources that are non-defense TRU cannot be disposed at present and should be stored until a viable disposition path for DOE non-defense TRU is established.
4. The development of a Standard Waste Box as a container to both transport and dispose neutron sources should be pursued. It is recommended that DOE begin the process to design, certify, and license this container.

8.0 Appendices

Appendix A – The Updated Neutron Source Database, contributed by George Bailey

Appendix B – Radioactive Source Recovery Program, History, Drivers, Requirements, and Goals, contributed by Joel Grimm, DOE/AL

Appendix C – Charter - Trade Study on Disposition of DOE Neutron Sources and Meeting Attendance

Appendix D – Heavy Isotope Program Acceptance Policy for Return of ^{252}Cf-Containing Neutron Sources, contributed by Joe B. Knauer, Jr., ORNL

Appendix E - Neutron Sources as Low-Level Waste, contributed by Susan Krenzien, HAZMED

Appendix F – WIPP Waste Acceptance Criteria

Appendix G – OSRP Acceptance Criteria, contributed by Lee Leonard, LANL

Appendix H – Cf-252 Shipping Containers at the REDC, contributed by Joe B. Knauer, Jr., ORNL

Appendix I – Type B Potential Neutron Source Packagings

Appendix J – "Simplified Neutron Shielding Calculations for Small Sealed Neutron Sources in 6M and S100 Type Containers"

Appendix K - Decision Analysis

Appendix L – Sensitivity Evaluation of Decision Analysis Results

Appendix M - Neutron Source Treatment at ANL-West in the Electrometallurgical Spent Fuel Treatment Process, contributed by Michael F. Simpson, ANL-W

Appendix N - Options for Disposal of Sealed Neutron Sources at SRTC, contributed by Frank Graham, SRTC/WSRC

9.0 References

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[DOE, 2001a] "Safety Analysis Report for the TRUPACT-II Shipping Package, Westinghouse TRU Solutions for DOE/CFO, TRUPACT-II SAR," Rev. 19, May 2001.

[DOE, 2001b] "Guidebook to Decision-Making Methods," Developed for the Department of Energy, U.S. Department of Energy, Washington, DC, September, 2001.

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Appendix A. The Updated Neutron Source Database

Contributed by George Bailey

Introduction

The primary source of information on neutron source inventories used in this Trade Study was the NISS database of sources. The NISS database was developed during the NMI Project, during which inventories of many nuclear materials were determined or verified. The data were obtained during 1997-1998, and were considered to be potentially out of date at the time of the Trade Study (mid-2001). Accordingly, those invited to be a part of the Working Group were asked to update the neutron source data for their site. Some sites provided complete updates to the source database, some provided updates only to their neutron sources, and some provided no update at all. This appendix describes the update process and presents some information obtained from the updated inventory.

The Update Process

In effect, the update involved comparing the two inventories representing two points in time – the 1997-1998 NISS database and the current inventory data supplied by the sites. In the comparison, five outcomes were possible for each record:

1. The ID of the record in the update information (henceforth the "new record") could not be found in the NISS database. In this case, the record was marked as "New" and the corresponding source was considered an addition to the inventory.
2. The ID of a record in the NISS database (henceforth the "old record") could not be found in the update. In this case, the record was marked as "Gone" and the corresponding source was considered to have been disposed or transferred to another site. No attempt was made to locate sources at the site to which they were transferred.
3. The ID of a new record could be matched to the ID of an old record and the data in the fields (primarily material, activity, and description) of the two records were essentially the same. In this case, the old record was passed into the updated database essentially unchanged.
4. The ID of a new record could be matched to the ID of an old record but the data in the fields (primarily material) of the two records were different. In this case, the new record replaced the old record.
5. The ID of a new record could be matched to the ID of an old record and the data in the fields (other than material) of the two records showed some differences. In this case, the data from the new record was used to update the old record.

This process assumes that inventories are complete and that source IDs are unique. A significant effort during the update process was devoted to avoiding duplicate IDs and to properly defining the "population" involved in the update. Other than that, the data were accepted as provided and, in general, the update considered "new information" to be better than old information. Table A-1, on the next page, shows some statistics from the update. The column headings may be interpreted as follows:

- Prior: The number of relevant records in the NISS database. Normally, this would be the number of records of neutron sources. In some cases, a broader population was used to account for changes in designation from "Actinide Source" to "Neutron Source."
- Gone: Records from the NISS database not appearing in the update – see #2, above.
- Original: Records from the NISS database that were passed unchanged into the updated database. See #3, above.

- Updated: Records from the NISS database that had some information changed in the Update. See #5, above.
- Replacement: Records from the update that replaced records from the NISS database. See #4, above. Ordinarily, one would expect an equal number of records labeled "Replaced" to account for the ones superceded by the replacements, but in every case the replaced record was not that of a neutron source and was therefore not counted.
- New: Records in the update not appearing in the NISS database. See #1, above.
- Current: The current neutron source inventory according to the information provided.

Table A-1

Neutron Source Database Update Statistics

Site	Prior	Gone	Original	Updated	Replacement	New	Current
ANL-E[1]	52		52				52
ANL-W	19	5	12	2	2	10	26
BNL[1]	77		77				77
ETTP	8	2		6			6
FNAL	18	12	1	5		1	7
Hanford	30	22		8	1	11	20
INEEL	7	7				72	72
LANL[1]	245		245				245
LBNL	56	16	22	18		1	41
LLNL	46	15	31				31
Mound[2]	23		23				23
NTS	98	56		42		34	76
ORNL	34	5		29		60	89
Pantex	29	10	19			1	20
PNNL	125	74	1	50[4]		2	103
SNL	58	9		49		35	84
SRS	159	63	79	17		37	133
Y-12	61	34		27		6	33
Other[3]	38		38				38
Totals	**1183**	**330**	**600**	**253**	**3**	**270**	**1176**

Notes:
1. No update provided.
2. Mound sources have been removed from the site. Many are believed to be at LANL. Since no update was provided by LANL, the Mound sources, some of which are rather large, have been included for completeness. Rocky Flats and Fernald sources were not included and, even if not counted, are not expected to affect the validity of the Trade Study.
3. No update was requested from the other sites.
4. During the update 8 items at PNNL were identified as having 58 sources, whereas previously they had been considered to be single sources.

It is important to reiterate that the update depended on sites having unique IDs for their sources and having a source numbering scheme that did not change during the 3-4 years since the NISS information was collected. Also, the statistics above relate to records, not sources. It is likely that many of the 270 "New" sources are actually to be found in the 330 that are "Gone" and that the failure to connect them lies at least partly in the source numbering schemes used.

Characterization of the Neutron Source Inventory

Table A-2 summarizes the neutron inventory by material and source activity. The bulk of the activity is contained in a few large sources. Most of the sources larger than 100 Ci are at the Bettis Atomic Power Laboratory. There is another significant grouping around 30-60 Ci, which is representative of the Mound sources and sources at some other sites. In the table, the term "mix" means other isotopes are included. In the americium sources, the other radionuclide is generally ^{137}Cs, which makes a moisture/density probe. ^{133}Ba and ^{137}Cs are usually found in the californium sources and the ^{239}Pu sources generally have other Pu isotopes.

Table A-2. Distribution of Neutron Sources by Material and Activity[a]

Material	All	<5 mCi[b]	>1 mCi	>1 Ci	>28 Ci	>54 Ci	>100 Ci
^{241}Am-B	2/4.3		2/4.3	2/4.3			
^{241}Am-Be	290/379	8/11	267/379	73/346	1/50.2		
^{241}Am -Be-mix	13/0.4		13/0.4				
^{241}Am -F	4/4.2		4/4.2	1/1.3			
^{241}Am -Li	134/651		134/651	59/620	3/300	3/300	1/101
Total ^{241}Am	**443/1039**	**8/11**	**420/1039**	**135/972**	**4/350**	**3/300**	**1/101**
Cf-252	426/92.5	179/182	82/92.5	12/89			
Cf-252-mix	7/0.002						
Total ^{252}Cf	**433/92.5**		**82/92.5**	**12/89**			
^{244}Cm-Be	1/11		1/11	1/11			
^{244}Cm -O	55/782		55/782	55/782			
Total ^{244}Cm	**56/793**		**56/793**	**56/793**			
^{238}Pu-B	2/25.3		2/25.3	2/25.3			
^{238}Pu-Be	94/7500	1/<1	92/7500	82/7497	56/7270	36/6509	16/5263
^{238}Pu-F	2/25.3		2/25.3	1/25.3			
^{238}Pu-Li	15/294		15/294	13/293	2/179	2/179	1/113
Total ^{238}Pu	**113/7845**		**111/7845**	**98/7841**	**58/7449**	**38/6688**	**17/5376**
^{239}Pu-Be	71/271	1/2	70/271	27/244	2/109.4	1/57.2	
^{239}Pu-Be-mix	8/24.3		8/24.3	5/24.1			
^{239}Pu-F	4/1.2		4/1.2				
^{239}Pu-F-mix	1/6.5		1/6.5	1/6.5			
^{239}Pu-O-mix	24/27.6		24/27.6	8/23.5			
Total ^{239}Pu	**108/330**		**107/330**	**41/298**	**2/109.4**	**1/57.2**	
^{226}Ra-B	2/3.2		2/3.2	2/3.2			
^{226}Ra-Be	20/11		18/11	4/8.0			
Total ^{226}Ra	**22/14.2**		**22/14.2**	**6/11.2**			
^{228Th}-Be	1/--						
Totals	***1176/10114***	***189/195***	***796/10114***	***348/10004***	***64/7908***	***42/7045***	***18/5477***

a. Excludes RFETS and Fernald inventories, but includes Mound. Table entries are given as (number of sources)/(total activity in curies), so an entry of 2/4.3 means 2 sources with a combined activity of 4.3 Ci.

b. All activities in this column only are in micro-curies (μCi).

The <5 μCi grouping in Table A-2 represents sources that, by themselves, might be considered LLW. To arrive at this value, it was assumed that the source weighed 10 grams – a reasonable weight for a source about 1 cm in diameter. To qualify as LLW, the activity should not exceed 100 nCi/gm, or 1 μCi for a 10-gram source. However, it is the average activity that is important, not the maximum, and for the sources in this inventory, a maximum value of 5 μCi yields an average value of about 1 μCi.

Sources smaller than 28 Ci are believed to be shippable because there are containers that can be used to transport materials with this activity. However, this is a designation based on activity alone, and there are other factors that determine whether the source can, in fact, be shipped.

Sources larger than 28 Ci pose a transportation problem, in addition to whatever disposition issues may attend them. Table A-3 provides additional details for these large sources. The greatest Curie content is found at Bettis, but significant activities are also present at SRS, Mound (now believed to be at LANL), and BNL. The other large sources seem to occur only one or two at a time.

Table A-3
Large Sources (>28 Ci)

Material/Site	Sources	Activity
^{241}Am-Be		
BNL	1	50
^{241}Am-Li		
LANL	1	100
LBNL	2	199
^{244}Cm-O		
PNNL	5	235
^{238}Pu-Be		
Bettis	12	4644
BNL	18	672
LANL	1	61
LLNL	3	270
Mound	16	937
NTS	2	110
SRS	4	554
^{238}Pu-Li		
ANL-E	1	113
LBNL	1	66
^{239}Pu-Be		
LANL	1	57
LBNL	1	52

Disposition options for sources can involve whether or not the source has a history of use in Defense Programs. Sources with such a history are eligible for disposition at WIPP, while those without that "pedigree" are not, at least according to the legislation surrounding that facility. Unfortunately, there is not a clear categorization of neutron sources with respect to their Defense history. Consequently, there cannot be a clear categorization of disposition options available for each source.

However, a preliminary effort at such a categorization, based only on source material, activity, and Defense history, is provided in Table A-4. First, californium sources pose the greatest likelihood for reuse. However, some californium sources are small enough for disposal as LLW. Those that can be disposed as LLW are placed in that category, even though government or commercial reuse options may be or become available. Those few americium and plutonium sources that meet the <5 μCi criterion are also placed in the LLW category. It is believed that the radium and thorium sources can be "diluted" sufficiently with other waste to be disposed of as LLW. Sources smaller than 28 Ci and possessing a Defense history can be directly disposed in WIPP, so long as the site has a capability to ship to WIPP. There are about 100 sources in this category (about 250 Ci). There are about 430 sources (~1450 Ci) of a similar size with unknown defense pedigree, a significant fraction of which are likely eligible for disposal in WIPP. About half of the large sources have a defense history (it has been assumed for the Bettis and Mound sources) and could be disposed in WIPP, assuming transportation considerations can be successfully addressed. Approximately an equal number are of unknown history, a significant fraction of which are likely disposable at WIPP. This leaves the category popularly known as "non-defense TRU." These cannot be disposed at WIPP, and based on current guidelines, are not acceptable to the OSRP, although they would be accepted if so directed by DOE/AL. There are about 100 sources (nearly 200 Ci) smaller than 28 Ci and 4 of the larger sources (~400 Ci) in this category.

Table A-4
Approximate Disposition Categories, Based on Size and Defense History

Disposition	Re-Use	LLW	WIPP	Possible WIPP	WIPP or OSRP	WIPP? or OSRP?	N-D TRU Shippable	N-D TRU Non-Ship
Criteria		<5 µCi	Defense <28 Ci	Unknown <28 Ci	Defense >28 Ci	Unknown >28 Ci	NonDef <28 Ci	NonDef >28 Ci
^{241}Am	?	8 11µCi	49 48 Ci	311 561 Ci		4 350 Ci	82 80 Ci	
^{252}Cf	254 92.6 Ci	179 182 µCi						
^{244}Cm	?			50 547 Ci		5 235 Ci		
^{238}Pu	?	1 <1 µCi	23 146 Ci	26 195 Ci	36 6254 Ci	20 846 Ci	4 54 Ci	2 348 Ci
^{239}Pu		2 2 µCi	35 59 Ci	49 121 Ci		1 57 Ci	22 41 Ci	1 52 Ci
^{226}Ra		22 14 Ci						
^{228}Th		1 --						

Appendix B

Note that appendices cited in the following document refer to the original appendices for the published paper and have not been included in Appendix B of this Neutron Source Trade Study.

(Contributed by Joel Grimm, DOE/AL)

RADIOACTIVE SOURCE RECOVERY PROGRAM

History, Drivers, Requirements, and Goals

Office of Waste Management (EM-30)
January, 1999

Introduction

The Radioactive Source Recovery Program's (RSRP) purpose is to fulfill the Department of Energy's (DOE) obligation to accept and manage sealed sources and devices, which exceed the U.S. Nuclear Regulatory Commission's (NRC) limit for class C radioactive waste.

The RSRP is currently under review and development at the Albuquerque Operations Office (AL). This program has a long and complicated history and the requirements are often misunderstood. The program has been a Headquarters effort until fiscal year (FY) 1999 where the day-to-day management has been transitioned to AL. The purpose of this document is to provide the history of the program to AL and the contractors who will carry out the program, provide information and analysis of the program drivers, provide clear program requirements, and provide the goals and expectations of the Office of Waste Management (EM-30) for this program.

At the time this document was prepared, AL was in the process of re-evaluating the program plans. The requirements section of this document provides items, which must be a part of the program regardless of the approach taken, or the methodology used to carry out the program. These items define the RSRP and must be included in any program plan.

The document begins with a history of the program, followed by a detailed analysis of the major documents driving the program, and concludes with requirements and goals.

I. History:

On January 15, 1986, the Low-Level Radioactive Waste Policy Amendments Act of 1985, Public Law (PL) 99-240, was signed into law. The primary intent of this legislation was to improve the procedures for implementation of compacts between states to establish regional low-level waste disposal sites. In Title I, Section 3, the act lays out responsibilities for the disposal of radioactive waste, making states responsible for most low-level waste generated within their borders. In defining these responsibilities, the act lays out the responsibilities for the Federal Government and assigns these responsibilities to DOE (see Appendix A).

Among other things, this law makes DOE responsible for the disposal of all non-DOE radioactive waste, which exceeds the U.S. Nuclear Regulatory Commission's (NRC) upper limit for licensed shallow land burial. These limits are found at Title 10, Code of Federal Regulations, Section 61.55. Radioactive waste, which exceeds the NRC limit for commercial disposal is commonly referred to as Greater Than Class C (GTCC) waste.

PL 99-240 required a report to Congress from DOE describing how DOE was going to fulfill its obligations under the law. The report, "Recommendations for Management of Greater-Than-Class-C Low-Level Radioactive Waste", DOE/NE-0077, February 1987, provides the basis for the program that would follow (see Appendix B). Since GTCC waste exceeds the NRC limits for shallow land burial, a more rigorous disposal method is required for GTCC waste. DOE concluded that it will take at least a decade to develop the disposal capability required. Recognizing that there is no other legal option for licensees and other agencies except to store their GTCC waste, DOE committed to Congress to have a program in place for accepting GTCC waste within 2 years, which would have been February, 1989.

Also in 1989, the Office of Environmental Restoration and Waste Management, now Environmental Management (EM), was created. The responsibility for GTCC waste transferred from the Office of Nuclear Energy to EM. At the same time, the NRC became concerned over the lack of a legal disposal option for GTCC wastes. Their greatest concern, both then and now, is sealed sources. Between 1989 and 1992, a number of meetings were held between NRC and EM. The NRC's concerns were based upon the following:

- NRC had been mandated by Congress to raise license fees;
- The current (1990) economic recession;
- Significant cutback in continental U.S. oil exploration (impacting well-logging); and
- Increase in manufacturing standards for Americium-Beryllium (Am/Be) well-logging sources making a large number of sources unfit for use (see 10 CFR 39).

The above factors, combined with the small size of most sources, the large number of small business licensees, and no legal disposal outlet could all lead to an increase in abandonment or illegal disposal. The end result of the meetings between NRC and EM was the letter agreement of April 7, 1992 between NRC and EM (see Appendix C). The agreement promises a storage capability by 1993 with an ability to accept up to 300 sources per year. It also created an interim measure by which EM would accept for management radioactive material from licensees if NRC determined that there was a threat to the public health and safety or that the licensee was on the verge of losing control of the material. The 1993 date for a storage capability was not met.

Responsibility for carrying out the letter agreement was placed in the Headquarters (HQ) Off-Site Waste (OSW) Program in EM-30. This program had the responsibility for responding to requests from other agencies for the return of DOE-owned materials, and all other issues dealing with waste management problems not on a DOE site. Since that time, the HQ OSW Program has responded to more than 15 requests from the NRC. The arrangements governing the process for NRC to request assistance from EM is provided in the Memorandum of Understanding (MOU) (see Appendix D). At the time of this document, EM-30 had signed the MOU and forwarded it

to NRC for signature. Information on the requests from NRC and the disposition of the materials is available upon request.

The HQ OSW Program noted immediately that a large number of requests were involving Am/Be sources used in the well-logging industry. At this point in time, the HQ OSW program was only tasked with responding to NRC requests as far as GTCC waste was concerned. The National Low-Level Waste Program was tasked with developing any storage or disposal solutions for GTCC waste. The HQ OSW Program began to look at possible solutions to the problem of GTCC sealed sources because it was becoming difficult to provide proper response to the NRC requests without a long-term solution.

In looking for a solution to the sealed source problem, the Plutonium-239/Beryllium (Pu-239/Be) Neutron Source Recovery Project at LANL was looked at by the HQ OSW program in 1994. After initial review, it was determined that although the existing program did not meet the HQ OSW Program needs, it could be expanded upon and upgraded. The most significant factors needing change were the high cost and the low number of sources accepted per year.

The next several years included ongoing efforts by the HQ OSW Program to receive approval and funding to develop a solution for the sealed source program. Enough funding was obtained each year to respond to expected NRC requests and engage in program development activities at LANL. Early program development activities included the preparation of an Environmental Assessment and the resulting Finding of No Significant Impact (see Appendix E). At this point the RSRP came to encompass all the sealed source issues, and the OSW program was included as additional work for the field (as opposed to HQ). The OSW program included the return of all DOE-owned materials, which were in the hands of colleges, universities, and other entities. Most of these items were part of loan-lease programs.

In 1997, the RSRP was at the point that several decisions needed to be made concerning how sources were going to be recovered. It was determined that one method was to hire a private sector licensed company to act as a consolidator. This company or companies would collect the sources from the licensees, store them at a licensed facility, remove any items so that only the source was packaged, and package sources by manufacturer and model so that processing would be eased by doing batches of like sources. The consolidator would then ship sources in bulk to LANL for processing. A request for proposal was issued, but due to a misinterpretation, none of the bids were in an acceptable price range. The bids were supposed to be to demonstrate a companies ability to pick up sources by going and retrieving up to 40 sources. NRC and EM-30 had determined a list of high priority sources which would be picked up as a pilot program to evaluate the idea of consolidation. Even though the bids were unacceptable, it was determined that LANL could still gather valuable information by recovering the sources. Appendix F contains the guidance letter to LANL to perform the pilot program. Five sources were recovered at the end of FY 1997. In FY 1998, additional guidance was issued to recover an additional 40 sources. At the time of this writing, the pilot program is scheduled to be completed in the first quarter of calendar year 1999.

Appendix G includes copies of the funding guidance each year for program development. LANL staff proposed the receipt, storage, and processing of sources in the CMR facility at

LANL in 1994. The HQ OSW program pursued developing a program based upon the LANL proposal until early 1998.

In 1996, the roles and responsibilities for the sealed source program were identified and established by EM-30. The memorandum establishing the roles and responsibilities between the source program and the National Low-Level Waste Program are in Appendix H.

In 1998, issues arose concerning the role of the Low-Level/Mixed Low-Level Waste Center of Excellence. Guidance clarifying the Center's role in sealed source programs is provided in Appendix I.

II. Requirements:

This section focuses on requirements for the RSRP. OSW program requirements are available upon request.

Legislation:

The main driver for the program is the Low-Level Radioactive Waste Policy Amendments Act of 1985, PL 99-240. Title I, Section 3(b)(1) states that the Federal Government shall be responsible for the disposal of the following:

> (A) low-level radioactive waste owned or generated by the Department of Energy;
> (B) low-level radioactive waste owned or generated by the United States Navy as a result of the decommissioning of vessels of the United States Navy;
> (C) low-level radioactive waste owned or generated by the Federal Government as a result of any research, development, testing, or production of any atomic weapon; and
> (D) any other low-level radioactive waste with concentrations of radionuclides that exceed the limits established by the Commission for class C radioactive waste, as defined by section 61.55 of title 10, Code of Federal Regulations, as in effect on January 26, 1983.

Section 3(b)(2) states: All radioactive waste designated a Federal responsibility pursuant to subparagraph (b)(1)(D) that results from activities licensed by the Nuclear Regulatory Commission under the Atomic Energy Act of 1954, as amended, shall be disposed of in a facility licensed by the Nuclear Regulatory Commission that the Commission determines is adequate to protect the public health and safety.

Section 3(b)(3) states that the Department of Energy must submit a report to Congress setting forth the Secretary's recommendations for ensuring the safe disposal of all radioactive waste designated a Federal responsibility in paragraph (b)(1)(D). The report must also include:

> "(E) An identification of the options for ensuring that the beneficiaries of the activities resulting in the generation of such radioactive wastes bear all reasonable costs of disposing of such wastes...".

The act ends with the requirement that the Department of Energy must wait 90 days after the report to Congress is submitted prior to beginning to dispose of GTCC waste.

In summary, the legislation produces the following requirements particular to sealed sources:

1. DOE must develop a disposal capability.
2. GTCC waste must be disposed of in a facility licensed by the NRC.
3. Reasonable cost recovery must be analyzed and evaluated, at a minimum.

Requirement number 2 creates additional requirements. First, the term GTCC can only apply to NRC licensed waste. Therefore, it does not apply to any waste owned by DOE. This can create some confusion in terminology. The DOE term "transuranic waste" and GTCC waste overlap. DOE has specific requirements for its transuranic waste. DOE "defense" transuranic waste is to be disposed at WIPP. The WIPP legislation prohibits the disposal of non-defense waste. The combination of the requirements for GTCC and the requirements for WIPP create three distinct types of waste: DOE-owned defense transuranic waste, DOE-owned non-defense transuranic waste, and GTCC waste which fits the definition of transuranic. These three types of waste, although physically identical, have different requirements. Therefore, they must be segregated, particularly GTCC is to be segregated and not commingled with DOE-owned waste in order to meet the disposal requirements for GTCC.

Report to Congress:

The report's full title is: Recommendations for Management of Greater-Than-Class-C Low-Level Radioactive Waste: Report to Congress in Response to Public Law 99-240. On pages iv and v of the Executive Summary the report states: Until the time that GTCC low-level waste can be disposed, DOE plans to accept such waste as necessary, after adoption of appropriate waste acceptance criteria, and to safely manage such waste until disposal options are developed. Such management may include storage and any required treatment, packaging, and transportation prior to disposal. DOE will develop appropriate procedures related to this management and will assess appropriate fees for use of these services. DOE expects to have a program in place for accepting GTCC low-level waste for storage within 2 years. In the interim, DOE will consider requests for accepting GTCC low-level waste on a case-by-case basis.

This portion of the executive summary contains the major requirements applicable to sealed sources. The requirements the program must meet are:

1. DOE will accept GTCC waste prior to disposal capability being in place.
2. DOE management of GTCC will include storage, treatment, packaging, and transportation.
3. DOE will assess appropriate fees for the management services.

Both the legislation and the report to Congress address cost recovery. The legislation states that DOE is to evaluate options such that the beneficiaries of the GTCC disposal pay "reasonable" costs. The report to Congress states that DOE will assess appropriate fees. The program needs to analyze the legal and regulatory requirements surrounding cost recovery and develop a recommendation and cost recovery program, if appropriate. Since PL 99-240 mandates only

"reasonable" cost recovery options, this should allow the program to set a fee which is less than full cost recovery. This issue needs to be explored and a legal determination made, if appropriate. Given that DOE is almost 15 years late in developing this program, and argument could be made that 15 years of storage and NRC license fees while waiting for DOE to develop a program is an unreasonable cost to bear, and any additional fee is not reasonable. Therefore, the program should explore a sliding scale fee approach, if possible, so that no fee could be charged in applicable situations (i.e. licensee has no real assets) up to full cost recovery, if appropriate, for larger businesses that do benefit financially from the existence of the program.

Agreement with NRC:

The letter agreement of April 7, 1992 and the more recent MOU set up several requirements, which are:

1. The program must have the capability to respond to an NRC request to include retrieving the source from the owner, packaging the source, and transporting the source, as well as all the support requirements such as radiation control to perform the above tasks.
2. The program must be capable of responding to NRC requests in a timely manner. Although the time frames vary, the program should be capable of responding to an unusual case in a few days.
3. The program must be capable of handling a wide variety of material in a wide variety of forms. Although the MOU is targeted towards sealed sources, which are GTCC, it is not limited to just those items. The program must have contingency plans to handle other types of materials. Non-GTCC items are requested infrequently, but often enough that the program should have a defined method for accessing commercial disposal for these items.

The agreements with NRC create a number of items, which, although not requirements spelled out in the agreements, are necessary from a management viewpoint to successfully carry out the program.

1. PL 99-240 assigns the responsibility for low-level waste generated within a state to the states. Therefore, in order to maintain the split of responsibilities laid out by Congress, any time NRC requests DOE to take non-GTCC material, every effort should be made by DOE to ensure that it goes to commercial disposal. Deviation from this goal should be discussed with HQ.

2. The program should assess the types of sealed sources and their associated devices and develop a plan based upon the risk to the public health and safety the sources present. The following is the best estimate of source types and order of risk at the time of this writing. This should be updated as information becomes available.

NRC estimates that there are over 27,000 sealed sources which meet the definition of GTCC. The types of sources are ranked below in order of risk to the public.

1. Americium/Beryllium (Am/Be) well logging neutron sources which were decertified for use in well-logging under 10 CFR 39.41 in July, 1989. (Due to accidents and breached

sources, manufacturing and testing requirements were increased). Approximately 1000 sources.

2. All other Am/Be and other types of neutron sources (Pu-239/Be, Pu-238/Be). Approximately 5000 sources. This excludes radium/beryllium sources.
3. Transuranic sources, i.e. plutonium, americium, Pu-238 batteries and pacemakers, etc. Approximately 15,000-20,000 sources.*
4. Cesium, Strontium, and other non-transuranic sources. 1000-5000 sources.*

*These estimates are poor. No conclusive data is available on exact numbers of sources.

Other Requirements:

The program must address the fact that DOE has not established the necessary programs under the law and the report to Congress and that almost 15 years have passed in the interim. This passage of time has created the unique situation that licensees are reaching retirement age and wish to end their business practices.

The program's major focus is GTCC sources, which by definition are not owned by DOE, but are the property of licensees. Some licensees, such as colleges, universities, and other government agencies have sources under license, but which are the property of DOE. These sources are held under "loan-lease agreements", or other equivalent contractual mechanisms. DOE also owns sealed sources. Where there is a need for source management, which involves both GTCC sources as well as DOE sources, the program should attempt to accommodate both needs. This should not be seen as a justification for commingling of materials.

The source program should attempt to integrate its source activities with Off-Site Waste program activities where appropriate. The source program shall pursue the disposal of GTCC sealed sources. Such efforts to pursue disposal need to be done while keeping the National Low-Level Waste Program (NLLWP) informed of the efforts being pursued. The NLLWP is responsible for developing disposal capability for GTCC waste in general. The largest quantities of GTCC are activated metal components from commercial nuclear power plants. Although the NLLWP shall be kept informed of disposal efforts, there is no requirement to obtain consensus with this program. Disposal solutions for sealed sources may be independent from that for other GTCC waste and such solutions may not be appropriate for other types of waste.

The program will be dealing with licensees, state programs, federal agencies, local government agencies, and others. Most, if not all, of the people encountered will not be familiar with the inner workings of the DOE or its facilities and contractors. Therefore, the program needs a strong customer service focus to deal with licensees and make the acceptance of sources by the program as simple as possible. This aspect of the program shall be given careful consideration by DOE and customer satisfaction should be evaluated periodically. This aspect of the program should be made a required performance measure for the contractor, if possible and appropriate.

There is very little inventory data on commercial sealed sources. Several attempts have been made to perform comprehensive inventories of sources in the hands of licensees. None have been successful. The program should not attempt to establish an exact inventory without first

discussing the compelling drivers for such an effort with HQ. Instead of attempting to establish an inventory, the program should establish a database to record information when it becomes available. By having an appropriate database, the program should capture data from licensees and others who send sources to the program for management. Additional information should be recorded, particularly if the licensee has other sources they are not turning in for management at this time. Also, historical information should be maintained, either in the database or other appropriate formats, for future use. Such information can be used to establish special form criteria for sources or other information. The use of the Internet to gather information on sealed sources and provide "on-line" registration should be explored.

Appropriate records shall be kept so that when it is time to actually dispose of sources, or material recovered from sources, that the origin of the material to the program is known. Records shall be kept indicating at a minimum the identity of the licensee or other entity providing sources to the program. Additional information should be kept as appropriate.

The program, in order to meet many of the individual requirements above, must be capable of taking a large number of sources each year at a per unit cost which is as low as possible. Given that there are estimated to be approximately 30,000 sealed sources, which meet the definition of GTCC, the program needs to be able to take in an appropriate number of unwanted sources each year. Not all the 30,000 are unwanted, but current estimates identify that there are 3,000 to 6,000 sources, which could be taken immediately. The ability of the program to receive sources should be based on the currently available information. The ability to increase the scope of the program should be factored in the planning of the program.

Finally, efforts should be explored to provide a long-term end to the program or other solution. Instead of a situation where GTCC sources continue to be manufactured and then continue to be disposed of, the program should look at ways to break this cycle. The program should explore possible regulatory changes, such as that GTCC sources can only be leased, not sold, therefore only a few manufacturers would be interacting with the program, or eventual privatization of the program. The program shall evaluate a range of options and pursue a plan to provide a long-term solution to the sealed source problem, which does not necessarily require an on-going federally funded program.

Appendix C

CHARTER
TRADE STUDY ON
DISPOSITION OF DOE NEUTRON SOURCES

Purpose: To identify preferred disposition paths for excess DOE-owned neutron sources by updating inventories and evaluating alternative disposition paths. Different alternatives may be identified for different types of sources.

Background: DOE sites hold a small, but significant number of neutron sources that are excess to their needs and for which no viable disposition path(s) have been identified. Most of these neutron sources consist of an alpha-emitting radionuclide such as Americium-241 and a light element such as beryllium and are called "(α,n) sources." Some of the radioactive materials are SNM, with special disposition and accounting issues. Another type of neutron source, often made with Californium-252, relies on spontaneous fission for production of neutrons. Although a disposition path is in place for some of these sources, others may not qualify and could require consideration. Selection and implementation of a disposition path for these sources is vital, and possibly critical path to site closures and risk reduction.

Working Group Membership:

Dean Bartlett	Hanford	Non-voting	
Tony Bindokas	CH	Voting	
Allen Blancett	SRS/SRTC	Non-voting	
Mike Clancy	BNL	Non-voting	
Greg Clark	RL	Voting	
Chuck Grigsby	LANL	Non-voting	
Joel Grimm	AL (OSRP)	Voting	
Steve Hamp	AL (NTP)	Voting	
Joe Knauer, Jr.	ORNL/OR	Voting	
Susan Krenzien	NV	Voting	
Terri Lang	ANL-E	Non-voting	
Lee Leonard	LANL (OSRP)	Non-voting	
Jim Low	AL	Voting	
Gary Peterson	EM-21	Voting	
Tim Pflaum	DP-253	Voting	
Tam Tran	SR	Voting	
Gary Polansky	SNL	Non-voting	
Bill Wilcox	LLNL	Non-voting	
Phil Wong	OAK	Voting	

Scope: The scope encompasses all types and sizes of DOE-owned neutron sources. Emphasis will be placed on sources known to be excess to current needs and those anticipated to become excess prior to completion of the Weapons-Usable Fissile Materials Disposition Program. Non-DOE owned (commercial) neutron sources are not considered in this study. However, a close interface will be maintained with the Project currently handling such sources as some DOE sources may be eligible for that Project. Spontaneous fission sources will be considered only if they are not acceptable to the viable disposition path at Oak Ridge. All reasonable disposition alternatives for sources are to be considered, including reuse, processing/recovery, disposal in WIPP, disposal as LLW, etc.

Discussion: DOE sites hold about 630 large (>1mCi) and 300 small neutron sources, most of which are excess to their needs. Disposition paths for these sources are primarily dependent upon the radionuclide in the source.

Most of the curie content in those that contain californium-252 and generate neutrons through spontaneous fission is expected to go to Oak Ridge, where the sources will be evaluated and dispositioned in an existing program. The (α,n) sources, consisting of an alpha-emitting radionuclide and a light element, do not have, or no longer have viable disposition paths. Those containing Pu-239 were to be processed by the Radioactive Source Recovery Program (RSRP) at Los Alamos National Laboratory (LANL) and the plutonium dispositioned by the Fissile Materials Disposition Program. Those containing Pu-238 or Am-241 were to be processed by the RSRP and the Pu-238 and Am-241 recovered for future programmatic use. However, the RSRP has been assimilated into the Off-Site Source Recovery Project (OSRP), which is concerned primarily with the licensed sector, and the processing function has been discontinued. As a consequence, the identified disposition paths for these DOE sources are no longer available, although some sources may be eligible for the OSRP. Also, there are no established disposition paths for neutron sources using other alpha-emitting radionuclides, such as polonium. Finally, a disposition path has not been established for spontaneous fission sources that are not accepted by ORNL.

Interfaces: All sites and laboratories with DOE-owned neutron sources will be considered interfacing sites.

There is also an interface with the OSRP. That Project considers two primary disposition paths: storage pending disposition and, for sources with a defense "pedigree," disposal at WIPP. It is possible that this trade study could identify additional alternatives for the OSRP. Also, the OSRP can accept DOE sources that meet certain criteria, and those sources may be assigned to the OSRP as the preferred alternative.

General Description of Trade Study: It is anticipated that the Trade Study will be completed by the end of the calendar year. The first phase, which involves developing the infrastructure for the Trade Study, performing certain technical and legal studies, and preparing and coordinating the first meeting, in May, is now largely complete. One outcome of that meeting will be an updated and agreed-upon inventory of excess neutron sources at each site. Also during that meeting possible alternative disposition paths will be screened to select a few "candidate" disposition paths for each source type that are relatively low in cost and risk. Following the first meeting the various candidates paths will be evaluated by small teams made up of members of the Working Group. Based on these evaluations, preliminary preferred alternatives will be established. At a subsequent meeting in July or August the evaluations will be reviewed for consistency and completeness and the preferred alternative(s) will be finalized. This meeting could also be used to critique the draft Trade Study report. A revised draft of the report will be prepared, based on that critique, and circulated for review and comment. Resolutions to the comments on the revised draft will be developed and the report revised accordingly to create a final draft. A third meeting, probably in October or November, would be held to finalize the report. Within a month of the last meeting, the final report will be issued as a recommendation to senior management

Deliverables from the Trade Study will include the final report. Intermediate deliverables, other than drafts of the final report and materials prepared for the first meeting, are not anticipated.

Milestones:

Assumed Start: February, 2001

First Meeting: May 23 & 24, 2001

Second Meeting: July/August, 2001

Third Meeting: October/November, 2001

Briefings to Management: October/November, 2001

Final Report: December31, 2001

Study Lead: The Trade Study will be led by Jim Low, of AL/NMSPO. G. D. Roberson, also of AL/NMSPO, will serve as Steering Committee liaison.

Attendance at the 1st (May 23-24, 2001), and 2nd (August 29-30, 2001)
NSTS Working Group Meetings

Representative	Organization	5/23-24	8/29-30
Jeff Allender	SRS	**X**	**X**
Bob Alvord	OAK/NNSA		**X**
George Bailey*	SNL/SCIENTECH	**X**	**X**
Dean Bartlett	Hanford	**X**	
Allen Blancett	SRS	**X**	
Mike Clancy	BNL	**X**	
Greg Clark	RL	**X**	**X**
Dale Dietzel	CH	**X**	
Frank Graham	SRTC/WSRC		**X**
Joel Grimm	*AL (OSRP)*	**X**	**X**
Chuck Grigsby	LANL	**X**	**X**
Greg Johnson	DOE/SRS/AMMFS/NMMD		**X**
Joe Jones*	SNL		
Brent Ives	*LLNL*	**X**	
Joe B. Knauer, Jr.	ORNL	**X**	**X**
Susan Krenzien	NV	**X**	**X**
Lee Leonard	*LANL (OSRP)*	**X**	**X**
Shelby Leonard	*LANL (OSRP)*		**X**
Jim Low	AL/NMSPO		**X**
Mark McAllaster	SNL	**X**	
Frank Montoya	*LANL (OSRP)*		**X**
Cathy Ottinger*	SNL	**X**	**X**
David Parks*	INEEL	**X**	**X**
Gary Peterson†	EM-21	**X**	
Gary Polansky*	SNL	**X**	**X**
Larry Sanchez	SNL	**X**	**X**
Joe Schelling*	SNL		
James Schreiber	*SNL*		**X**
Bob Seidel	ANL (W)		**X**
Michael Simpson	ANL (W)		**X**
Tam Tran	SR	**X**	**X**
Bill Wilcox	LLNL	**X**	
Phil Wong	OAK	**X**	

* Decision Analysis Core Team Members

† Gary Peterson has since transferred to EM-30.

Appendix D

HEAVY ISOTOPE PROGRAM ACCEPTANCE POLICY
FOR RETURN OF ^{252}Cf-CONTAINING NEUTRON SOURCES

Contributed by Joe B. Knauer, Jr., ORNL

1. NEUTRON SOURCE RETURN POLICY

1.1 Cf-252 neutron sources fabricated at the Oak Ridge National Laboratory's Radiochemical Engineering Development Center (ORNL/REDC) under the provisions of the DOE-SC Transuranium Element Production Program (TEP) and provided on-loan to DOE integrated contractors are acceptable for return to ORNL.

1.1.1 All costs related to the return of a source, i.e., recertification testing, return to in-process inventory, special nuclear material accountability, and transportation, are the responsibility of the returning facility/agency.

1.1.2 Return costs are estimated and charged to the returning facility/agency on a Full Cost Basis (current FY).

1.2 Cf-252 neutron sources fabricated at Savannah River Laboratory (SRL) and/or ORNL/REDC under the provisions of the DOE-DP Californium Industrial/University Loan Program and provided on-loan to DOE integrated contractors; government agencies and NRC-licensees are acceptable for return to ORNL.

1.2.1 All costs related to the return of a source, i.e., recertification testing, return to in-process inventory, and special nuclear material accountability and transportation, are the responsibility of the returning facility/agency. Return costs (except those related to transportation) are waived for university and medical research loans.

1.2.2 Return costs are estimated and charged to the returning facility/agency on a Full Cost Basis (current FY) and are charged as a source loan fee at the initiation of the loan. Loan extension fees are assessed as required.

1.2.3 Transportation-related costs are the responsibility of the loanee (the returning facility/agency).

1.3 Cf-252 neutron sources fabricated at Savannah River Laboratory (SRL) and/or ORNL/REDC under the provisions of the DOE-DP/NE Californium Industrial Sales Program and provided on a sale basis to commercial encapsulators/vendors for purposes of resale to DOE integrated contractors for use in "not-for-profit" applications are acceptable for return to ORNL.

1.3.1 All costs related to the return of a source, i.e., recertification testing, return to in-process inventory, special nuclear material accountability, and transportation, are the responsibility of the returning facility/agency.

1.3.2 Return costs are estimated and charged to the returning facility/agency on a Full Cost Basis (current FY).

1.4 Cf-252 neutron sources fabricated at Savannah River Laboratory (SRL) and/or ORNL/REDC under the provisions of the DOE-DP/NE Californium Industrial Sales Program and provided on a sale basis to commercial encapsulators/vendors for purposes of resale to "for-profit" commercial companies, corporations, entities, etc. are not acceptable for return.

1.5 Exceptions to these return policies require "special" DOE approval and are considered on a case-by-case basis.

2. NEUTRON SOURCE RETURN TERMS AND CONDITIONS

2.1 The returning facility/agency (hereafter referred to as the returnee) requests/obtains DOE-ORO approval for all Cf-252 neutron source returns.

2.2 The returnee must notify ORNL/REDC and make the necessary arrangements prior to the return of any Cf-252 neutron source(s).

2.3 The returnee must attest/document that sources for return have not been exposed to (a) an external total neutron fluence greater that 10^{14} n/cm^2 or (b) a primary accelerator beam.

2.4 The returnee must provide documentation as to the integrity/condition of the source encapsulation, i.e., leak test results, surface contamination levels, visual inspection results, etc.

2.5 The returnee must provide a description (as complete as possible) of the source(s) for return including source identification, source design, encapsulation material, dimensions, any added attachments, source fabricator, fabrication date, etc.

2.6 The returnee must provide to the best of their knowledge a detailed characterization of the neutron source contents including the current ^{252}Cf content, isotopic composition of the material used for source fabrication, initial ^{252}Cf content and assay date, date of last separation from other actinides/lanthanides, etc.

2.7 The returnee must provide a detailed description of the uses to which the source(s) for return has been put and certify that the information is correct to the best of their knowledge.

2.8 The returnee agrees to be financially responsible for all applicable charges/costs related to the return of the source to ORNL/REDC. A detailed estimate of the costs associated with the return of a source(s) will be provided to the returning facility/agency by ORNL/REDC following receipt of the initial request for source return.

2.9 ORNL/REDC will provide the returning facility/agency with all forms (source utilization, source characterization, request for materials/services, etc.) necessary to initiate and document source returns.

Appendix E

NEUTRON SOURCES AS LOW-LEVEL WASTE

Contributed by Susan Krenzien, HAZMED

DOE has identified two regional low-level radioactive waste disposal sites: The Hanford Site (Hanford) and the Nevada Test Site (NTS). Each disposal site has a waste acceptance criterion in accordance with DOE Order 435.1, *Radioactive Waste Management*. The *Hanford Site Solid Waste Acceptance Criteria*, HNF-EP-0063, Revision 6, April 2001 is available at www.hanford.gov/wastemgt/wac/criteria.htm. The *Nevada Test Site Waste Acceptance Criteria*, DOE/NV-325 (NTSWAC), Revision 3, December 2001 is available at www.nv.doe.gov/programs/envmgmt/RWAP/NTSWAC.htm.

Hanford's acceptance process includes:

1. Obtaining approval from the Department of Energy to ship waste to the Hanford Site.
2. Providing a forecast of the expected waste volumes and arranging funding for the forecasted waste volumes yearly.
3. Providing information concerning each waste stream on a Waste Profile Sheet.
4. Providing specific data for each waste container on the Container Data Sheet.

A percentage of waste shipments and containers are selected for receipt verification. These containers can be inspected visually, verified by nondestructive examination, or sampled for field or laboratory analysis to confirm that the waste matches the Waste Profile Sheet.

Nevada's acceptance process includes:

1. Providing a waste certification program plan or quality assurance program plan with a NTSWAC Implementation crosswalk, and certification personnel list.
2. Providing information concerning each waste stream on a Waste Profile.
3. NNSA/NV conducting a on-site audit of waste certification program implementation. If corrective actions required they must be closed prior to program approval.
4. Contacting Bechtel Nevada Generator Coordinator for forecast and funding process.
5. Providing specific data for each waste container on the Package Storage and Disposal Request.

Specific to Neutron sources:

- Sources offered for disposal at either site cannot be classified as TRU waste. The determination instructions are found in Appendix A of Hanford's WAC and Section 3.1.14 of the NTSWAC.
- Sources offered for disposal at Hanford cannot exceed the radiological limits listed in Section 3.4.1 of the Hanford WAC. Stabilization or special packaging (high-integrity container) may be required prior to disposal. Packaging specifications include: packages and sacrificial rigging cannot contain regulated materials, such as lead and containerized waste must fill at least 90 percent of the internal volume of the container.
- Sources offered for disposal at the NTS cannot be mixed waste or DOE equivalent to Greater-than-Class-C. The sources can exceed the levels identified in Table E-1 of the WAC, however a Performance Assessment review would be required. Non-TRU nuclide sources under 100µCi can be placed in general waste streams. Those above 100µCi must be segregated and profiled as a separate waste stream. TRU nuclides sources must be characterized on an individual basis using the volume or mass of the source to determine the radionuclide concentration.

Appendix F. WIPP Waste Acceptance Criteria

Waste Acceptance Criteria for the Waste Isolation Pilot Plant (WIPP) are described in DOE/WIPP-069, which is available online at http://www.wipp.carlsbad.nm.us/library/wac/chwac.pdf. Information in this appendix is abstracted from Revision 7 of that document, dated 11/8/1999 (including Change Notices #1 [8/29/2000] and #2 [1/24/2001]).

WIPP Waste acceptance criteria for contact-handled TRU waste (CH-TRU) in that document in terms of six components:

- Container Properties
- Radiological Properties
- Physical Properties
- Chemical Properties
- Gas Generation Properties
- Data Package Contents

The WIPP WAC is summarized in Table F-1, which is based on Table 3.1 of DOE/WIPP-069. Those of most interest to the disposition of excess neutron sources are the criteria of a TRU concentration of at least 100 nCi/g, criticality considerations, decay heat (limited to 40W), and surface dose rate (limited to 200 mrem/hr).

It should be noted that the S100 was approved in Rev. 19 of the TRUPACT II SAR in CY2001. The S100 is currently undergoing changes in manufacturing technologies and these changes will be incorporated in Rev. 21 of the TRUPACT II SAR in CY2002. In Rev. 19, the S100 container was approved for shipping two isotopes used in neutron sources (^{238}Pu/Be, ^{239}Pu/Be, and ^{241}Am/Be).

Table F-1 WIPP Waste Acceptance Criteria

WASTE ATTRIBUTES	WASTE ACCEPTANCE CRITERIA
Container Properties	
Payload container description	U.S. Department of Transportation (DOT) Type A or Equivalent • 55-gallon drums (direct fill or containing a pipe component) • Standard waste boxes (SWBs) • Ten-drum overpacks (TDOPs)
Container weight and center of gravity	• DOT Type A or equivalent limits • TRUPACT-II limits from the SARP
Removable surface contamination	For individual payload containers, payload assemblies, and packagings • <20 dpm/100 cm^2 for alpha • <200 dpm/100 cm^2 for beta-gamma The fixing of surface contamination to meet these criteria is not allowed.
Container identification/marking	• Bar code label consisting of the site identification and a unique container identification number • Shipping category
Dunnage	• Empty 55-gallon drums • Empty SWB
Filter vents	• Payload containers vented using filter(s) that meet the WIPP Hazardous Waste Facility Permit and the TRUPACT-II SARP, appendix 1.3.5 specification
Radiological Properties	
Radionuclide composition	• Assay measurements • Quantification of ^{241}Am, $^{238}Pu^{239}$, Pu, ^{240}Pu, ^{242}Pu, ^{233}U, ^{234}U, ^{238}U, ^{90}Sr, and ^{137}Cs*
Fissile material quantity (^{239}Pu fissile gram equivalent [FGE])	• 200 g/55-gallon drum (direct fill or containing a pipe component) • 325 g/SWB • 325 g/TDOP • 325 g/TRUPACT-II • 2800 g/TRUPACT-II (fourteen 55-gallon drums each containing one pipe component)
TRU alpha activity concentration	• >100 nCi of alpha-emitting TRU isotopes per gram of waste.
^{239}Pu equivalent activity (PE-Ci)	**Untreated waste** • 80 PE-Ci/55-gallon drum • 130 PE-Ci/SWB • 130 PE-Ci/TDOP • 1,100 PE-Ci/55-gallon drum overpacked in a 85-gallon drum, or SWB, or TDOP • 1,100 PE-Ci/SWB overpacked in a TDOP • 1,800 PE-Ci/55-gallon drum containing a pipe component **Solidified/vitrified waste** • 1,800 PE-Ci/55-gallon drum
Radiation dose rate	• 200 mrem/h at the surface of the payload container and the TRUPACT-II. • 10 mrem/h at 2 m
Physical Properties	
Liquids	Free liquid • <1 volume percent of external container • <1 inch or 2.5 cm in bottom of internal containers
Sealed containers	• No sealed containers greater than 4 liters

WASTE ATTRIBUTES	WASTE ACCEPTANCE CRITERIA
Chemical Properties	
Pyrophoric materials	• <1% radionuclide pyrophorics • No nonradionuclide pyrophorics
Hazardous waste	• Characterization is in accordance with approved site-specific QAPP as defined in the WIPP WAP • Limited to RCRA hazardous waste codes listed in table 3.5.2.
Chemical compatibility	• No chemicals or materials that are incompatible
Explosives, corrosives, and compressed gases	• No explosives, corrosives, or compressed gases
Headspace gas volatile organic compound (VOC) concentrations	• Every container will be headspace gas sampled.
Polychlorinated biphenyl concentration	• <50 ppm
Gas Generation Properties	
Payload shipping category	All payload containers in a TRUPACT-II shall belong to the same shipping category.
Decay heat	• Decay heat limit for the authorized shipping category • 40 W per TRUPACT-II
Test category waste	• Steady-state hydrogen gas generation release rate is less than or equal to the rate specified in the TRUPACT-II SARP, appendix 1.3.7
Flammable VOCs	• 500 ppm total in the headspace of any payload container
Venting and aspiration	• Retrievably stored drums that have been stored in an unvented condition shall be aspirated before shipment for a length of time greater than or equal to time shown in the TRUPACT-II SARP
Data Package Contents	
Characterization and certification data	• WSPF and accompanying characterization data summary report • Waste container data imported to the WWIS
Shipping data	• Uniform hazardous waste manifest (UHWM)(1) or bill of lading • Land disposal restriction (LDR) notification(1) • Payload Assembly Transportation Certification Document (PATCD) and Payload Container Transportation Certification Document (PCTCD)

Notes:

(1) Applies only to shipments of RCRA hazardous waste

* Am – Americium, Cs- Cesium, Pu – Plutonium, Sr – Strontium, U - Uranium

Appendix G – OSRP Waste Acceptance Criteria

(Contributed by Lee Leonard, LANL)

(Adapted from OSRP presentation at Aug. 29-30, 2001 Neutron Source Trade Study Meeting.)

Major Accomplishments Since Last Meeting

1. Received NRC approval on Rev 19 of TRUPACT-II SAR.
2. Received NNSA/DOE-SO approval to terminate safeguards on Am-241 sealed sources.
3. Special Form Capsule Model-2 will undergo testing for approval this month {Aug., 2001).
4. Security issues on neutron sources containing Pu-239 remain unresolved, but progress is being made.

Action Items

Management of 15-60 Curie neutron sources

1. On a Work-For-Others Basis (Reimbursable), OSRP can accept all Am-241 and Pu-238 bearing neutron sources < 10 Ci, if they have a defense pedigree. Non-defense will be considered on a case-by-case basis.
2. On a Reimbursable Basis, OSRP will accept Am-241 and Pu-238 bearing neutron sources >10 <30 Curies with a defense pedigree when production of the S-100 container begins. (non-defense will be considered on a case-by-case basis)
3. Pu-238 neutron sources 30-60 Curie nominal activity, same as 2 above. (Most decayed to <54 Curie)
4. Am-241 neutron sources 30-54 Curie nominal activity, same as 3 above.
5. Am-241 neutron sources 54-60 Curie nominal activity will be considered on a case-by-case basis, only.

How OSRP WFO on neutron Source Acceptance Will Work

Utilize Integrated Work Order

Purchase Request through Respective Purchasing Departments (IWO)

>$250K through DOE Offices Funds Transfer

<$250K send order to LANL directly

- Susan Martinez (LANL) 505-667-0264 (phone)
  505-665-4853 (Fax)

Direct Disposal >60 Ci

Not possible at this time

1. No shielded container sufficient to meet contact limits. (200mRem/Hr on contact)
2. Need submitted to Nuclear Materials Focus Area for EM-50 funding.

Transportation Sources <60 Ci

1. By October 1, 2001, OSRP can qualify most any neutron sources as Special Form with the exception of unusual geometries. (longer than 19 inches, diameter > 2 inches)
2. Transport of neutron sources in Special Form up to approximately 45 Curies is possible in S-100 Pipe Component Overpack as DOT-Type A.
3. Transport of neutron sources in Special Form up to 60 Curies is possible in S-100 Pipe Component Overpack as DOT Exclusive Use.

Appendix H. Cf-252 Shipping Containers at the REDC[a]

Contributed by Joe B. Knauer, Jr., ORNL

Name (Serial No.)	Weight (lb.)	H x W (in.)	Inner Cavity (in.)	Shield Plug length (in.)	Insert cavity size, H x W (in.)	Shielding mat'ls (loading direction)	Special Form Required	Nominal max. ^{252}Cf content (µg)	DOT Type (Spec.)
10 gal. 6M drum	80	17 x 14	2R	N/A	N/A	Fiberboard (top)	No	5-6	Type B (6M)
5-gal. drum (US/M4492)	6	14 x 12	Isotope Can	N/A	N/A	poly-beads (top)	No	<1	Type A (7A)
SRL 55 gal. drum	650	36 x 24	2R (2 x 3.5)	13.5	4 x 0.5	WEP[b] (top)	Yes	100	Type A (7A)
Atkinson Steel (263)	300	20 x 18	Shield Plug (12 x 4)	8	2 x 0.44	WEP (top)	Yes	15	Type A (7A)
Atkinson Steel (262)	680	28 x 24	Shield Plug (15 x 4)	11	2 x 0.44	WEP (top)	Yes	50	Type A (7A)
Atkinson Steel (261)	1,220	34 x 30	Shield Plug (18 x 4)	14	2 x 0.44	WEP (top)	Yes	200	Type A (7A)
Atkinson Steel (122)	2,100	38 x 30	Shield Plug (22 x 4)	14	6.5 x 1.5	WEP (top)	Yes	500	Type A (7A)
Atkinson Steel (257)	3,180	46 x 42	Shield Plug (23 x 4)	16.5	6.5 x 1.5	WEP (top)	Yes	1,500	Type A (7A)
Atkinson Steel (241)	3,800	48 x 44	Shield Plug (29 x 4)	21	6.5 x 1.5	WEP (top)	Yes	3,000	Type A (7A)
Atkinson Steel (245)	3,800	48 x 44	Shield Plug (29 x 4)	21	6.5 x 1.5	WEP (top)	Yes	3,000	Type A (7A)

[a]Unless otherwise specified the shipping containers listed are government-owned and supplied on an as-available basis.
[b]Water-extended polyester, borated to provide more efficient neutron shielding.
[c]This shipping container is the property of Frontier Technology Corporation, Xenia, Ohio.
[d]This shipping container is the property of GE/Vallecitos Nuclear Center, Sunol, California.

(Continued on next page.)

Cf-252 Shipping Containers at the REDC[a]

(Concluded)

Name (Serial No.)	Weight (lb.)	H x W (in.)	Inner Cavity (in.)	Shield Plug length (in.)	Insert cavity size, H x W (in.)	Shielding mat'ls (loading direction)	Special Form Required	Nominal max. ^{252}Cf content (µg)	DOT Type (Spec.)
Atkinson Steel (252)	4,600	50 x 50	Shield Plug (28 x 4)	20	6.5 x 1.5	WEP (top)	Yes	3,000	Type A (7A)
Atkinson Steel (248)	4,950	50 x 50	Shield Plug (29 x 4)	25	6.5 x 1.5	WEP (top)	Yes	3,700	Type A (7A)
Atkinson Steel (127)	4,900	48 x 50	Shield Plug (29 x 4)	21	6.5 x 1.5	WEP (top)	Yes	3,700	Type A (7A)
FTC/50100[c] (008)	7,400	60.5 x 58	Shield Plug (21 x 6)	23	6.5 x 1.5	WEP (top/ bottom/side)	Yes	5,000	Type A (7A)
GE Model 2518[d]	7400	60.5 x 58	Shield Plug (21 x 6)	23	6.5 x 1.5	WEP (top/ bottom/side)	Yes	5,000	Type A (7A)
Snowball (L-23413)	9,550	75 x 62	Shield Plug (27 x 4)	21	5 3/4 x 1 3/8	WEP (top)	Yes	80,000	Type B USA/6642/B( )
Snowball (L-23353)	9,550	75 x 62	Shield Plug (27 x 4)	21	5 3/4 x 1 3/8	WEP (top)	Yes	80,000	Type B USA/6642/B( )
Cannonball (no S/N)	23,500	80 x 68	Shield Plug (34 x 3)	31	2 1/4 x 7/16 (5 positions)	concrete (top/bottom)	Yes	60,000	Type B USA/5740/B( )

[a]Unless otherwise specified the shipping containers listed are government-owned and supplied on an as-available basis.
[b]Water-extended polyester, borated to provide more efficient neutron shielding.
[c]This shipping container is the property of Frontier Technology Corporation, Xenia, Ohio.
[d]This shipping container is the property of GE/Vallecitos Nuclear Center, Sunol, California.

Appendix I. **Type B Potential Neutron Source Packagings**

NRC Certificate Number Model Cask Weight	Non-specific Neutron Sources	Pu Pu-238-Be, Pu-238-F, Pu-238-Li; Pu-239-Be	Am Am-241-Be, Am-241-Li	Cm Cm-244-Be, Cm-244-O	Ra Ra-226-B, Ra-226-Be	Th Th-228-Be
USA/9277/B( )F FSV-1 Unit 3 ~ 47,000 lbs	neutron source components					
USA/9261/B(U)F-85 HI-STAR 100 System ~ 282,000 lbs	Dresden Unit 1 with 1 Sb-Be neutron source					
USA/9218/B(U)F-85 TRUPACT-II with S100 ~ 650 / 19,250 lbs		need Rev. 21 SAR approval Pu-238-Be, Pu-239-Be 28 Ci	need Rev. 21 SAR approval Am-241-Be, 28 Ci			
USA/9216/B( )F CNS 1-13G ~ 25,500 lbs	neutron sources special form 500 gm U-235 equivalent & < 50 watts					
USA/9010/B( )F NLI-1/2 ~ 49,250 lbs	neutron source components wt < 1600 lbs. SNF					
USA/5805/B( ) CNS 3-55 ~ 70,000 lbs	Sb-Be neutron sources <250 watts < 2.3 Ci Sb-124 neutron sources					
USA/5757/B( )F S5W Refueling Source DOE Naval Reactors ~ 19,000 lbs		Pu-238-Be special form 3 sources < 925 Ci < 1.48E9 n/sec surface contam limited			Ra-Be special form 3 sources < 940 Ci < 2.5 Ci (gm) radium < 3.8E7 n/sec surface contam limited	
USA/0302/B(U) United Kingdom 0666AW, ~ 45 lbs import/export only		30 Ci Pu-238-Be 0.93 Ci Pu-239-Be	130 Ci Am-241-Be			

Note: the Cm-244, Ra-226, and Th-228 neutron sources are smaller and not likely to require Type B packaging, unless they are not special form.

Appendix J Simplified Neutron Shielding Calculations for Small Sealed Neutron Sources in 6M and S100 Type Containers

Excerpt (Appendices containing extensive code listings were deleted.) from Sanchez 2001.

ABSTRACT

A simplified methodology for analyzing the neutron shielding calculations of small sealed neutron sources within Type A containers (i.e., 6M, S100, etc,) was developed. The specific cases studied were – 1) 6M containers with and without additional internal shielding material and 2) extended geometry dimensions of the S100 pipe overpack. Key results indicated that significant amounts of neutron moderator material is needed in order to allow fast neutrons to scatter down to thermal energy neutrons, which can easily be removed by thermal neutron absorbers. Analytical solutions were obtained for the fast neutron component of the neutron leakage flux.

J.1 INTRODUCTION

In 1998, DOE/EM-60 initiated the Nuclear Material Integration (NMI) Project. This project is support by the Nonactinide Isotope and Sealed Source (NISS) team. One of the NISS goals is to inventory and analyze the neutron sources within the DOE complex. The present inventory contains greater than 1,000 neutron sources at the various NMI sites and laboratories. Future shipments of these neutron sources could be transported in – 1) existing licensed containers, 2) S100 pipe overpacks (within a TRUPACT-II), and/or 3) to-be-determined (TBD) containers. Many of these neutron sources are within existing containers or are within the current S100 pipe overpack envelope of 28 Ci. This analysis presents a simplified methodology for analyzing those sources that are not already in containers and/or within the S100 envelope.

There are various Type-A containers that can be used for the safe transport of very small neutron sources (< 1 mCi). Examples of these include the 6M containers, which are available in 10-, 30-, 55-gallon sizes (Edling 1975). The first part of this report analyses the neutron shielding performance of the 55-gallon 6M container (a very common container size) to identify its neutron source payload envelope. The later part of this report analyzes the shielding performance of hypothetical enlarged versions of the S100 pipe overpack for containing sources greater than the S100 payload limit of 28 Ci.

J.2 KEY TRANSPORTATION REQUIREMENTS

There are various transportation requirements on the radioactive components of the transport material. They include fissile mass, activity inventory, dose rate, etc. The external dose rate is the major contributor to short term human health risks to the radiation waste workers. These are dominated by the neutron leakage from the containers with a minor contribution due to secondary gammas (note, emitted charged particles such as betas and alphas are easily stopped by the container material).

The key transportation requirements for neutron sources are those associated with the dose rate external to the container. These dose rate requirements are:

- Non-Exclusive Use Shipment / Normal Conditions of Transport (NCT):
  1. Transport Index (T.I.) < 10
  2. Surface dose rate ≤ 2 mSv/hr (200 mrem/hr)
- Exclusive Use
  1. S100 and/or TRUPACT-II surface dose rate ≤ 2. mSv/hr (200 mrem/hr)
  2. TRUPACT-II dose rate (2 meters from surface) ≤ 0.1 mSv/hr (10 mrem/hr)
  3. TRUPACT-II dose rate (occupied space, assumed to be 5 meters from surface) ≤ 0.02 mSv/hr (2 mrem/hr)
- Hypothetical Accident Conditions (HAC)
  - TRUPACT-II dose rate (1 meter from surface) ≤ 10 mSv/hr (1,000 mrem/hr)

J.3 NEUTRON SOURCES

Figure J.3-1 identifies the neutron energy spectra for the plutonium-beryllium sources (other common neutron sources has similar spectra). The neutrons emitted are due to the (α,n) reactions in which an alpha particle from plutonium (most commonly ^{238}Pu and ^{239}Pu) nuclei interact directly with low-z nuclei (in this case, beryllium) resulting in the emission of a high-energy (fast) neutron (see Tables J.3-1 and J.3-2).

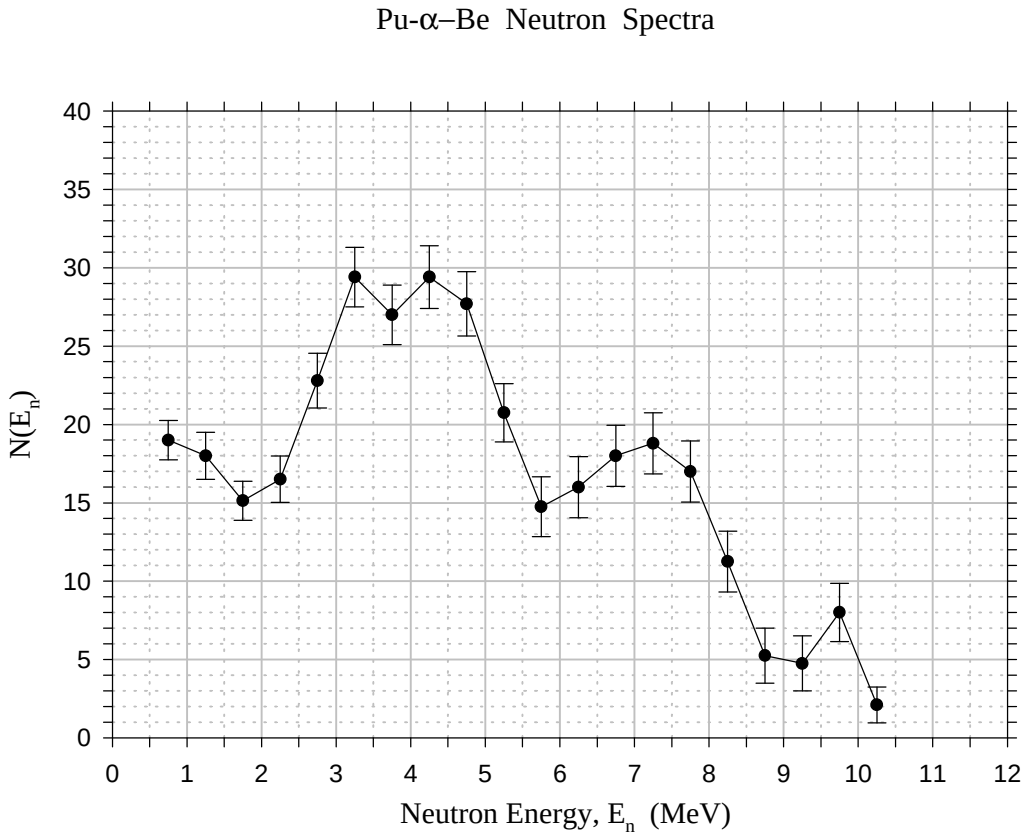


Figure J.3-1 Pu/Be Neutron Spectra (after Ref. Schleien 1998b, original source Patterson 1973).

Table J.3-1 Sources of Neutrons [a]

Source	Reaction	Average Neutron Energy (MeV)	Yield [b] (Gy/Ci)	Characteristic Problems
Ra + Be	α , n	Spectrum	3.0×10^4	α , γ , Rn
Ra + Be	α , n	5.0	3.0×10^4	α , γ , Rn
Ra + D_2O	α , n	0.12	3.0×10^4	α , γ , Rn
^{222}Rn + Be	α , n	5.	3.0×10^4	α , γ , Rn
^{210}Po + Be	α , n	4.	3.0×10^4	α
^{210}Po + B	α , n	2.5	3.0×10^4	α
^{210}Po + F	α , n	1.4	3.0×10^4	α
^{210}Po + Li	α , n	0.42	3.0×10^4	α
^{227}Ac + Be	α , n			α
^{239}Pu + Be	α , n	4.	3.0×10^4	α
^{252}Cf	Spon. Fission	Fission Spectrum	3.0×10^4	α , γ

(a) Data taken from Shleien 1998.

(b) For (α,n) reactions, yields are an indefinite function of target material and emitter mixing.

Table J.3-2 Characteristics of Selected Radionuclide Neutron Sources [a]

Source	Reaction	Half-life	Average Neutron Energy (MeV)	Yield per Bq (neutrons s^{-1}) [b]	Yield per Ci (neutrons s^{-1}) [b]
^{226}Ra + Be	α , n	1620. yr	4.0	351×10^{-6}	1.3×10^7
^{238}Pu + Be	α , n	86.4 yr	4.5	62×10^{-6}	2.3×10^6
^{241}Am + Be	α , n	458. yr	4.5	59×10^{-6}	2.2×10^6
^{210}Po + Be	α , n	138.4 d	4.2	68×10^{-6}	2.5×10^6
^{210}Po + B	α , n	138.4 d	^{10}B: 6.3	16×10^{-6} [c]	6.0×10^5 [c]
			^{11}B: 4.5		
^{124}Sb + Be	γ , n	60. d	0.024	35×10^{-6} [c,d]	1.3×10^6 [c,d]
^{252}Cf	Spon. Fission	2.65 yr	2.35 (fission spectrum)	62 (from 1 g) [e]	2.3×10^{12} (from 1 g) [e]

(a) Data taken from Shleien 1998.
(b) Compact mixtures.
(c) Relatively monoenergetic.
(d) Yield can be increased about four times by encasing in beryllium.
(e) Specific activity: 19.7×10^{12} Bq g^{-1} (532 Ci g^{-1}).

J.4 RADIATION TRANSPORT ANALYSIS

The two most common analysis methods for modeling neutron transport (and shielding) are – 1) use of the Boltzmann transport equation (via finite element or finite difference codes) or 2) non-analog Monte Carlo [Schaeffer 1973]. Since both of these approaches are beyond the scope of work for this study, the simple "Point Kernel" method was adopted. This method is commonly used for simple gamma shielding calculations (see Lamarsh 1983, Sanchez 2000) where an extended radiation source volume is integrated over all of its point source strengths convoluted with the attenuation kernel. For this study, the location of concern is the container mid-height plane (location of the maximum radiation flux and dose rates). This can be modeled by the simple one-dimensional radial-symmetric model is given by Equation J.4-1.

$$f = f_0 e^{-\Sigma_R t} = \frac{A e^{-\Sigma_R t}}{4\pi R^2} \qquad [Eq.\ \text{J.4-1}]$$

where

f = fast neutron flux of an unshielded uncollided isotopic point source (n/cm^2-s)

f = fast neutron flux of a shield uncollided isotopic point source (n/cm^2-s)

A = fast neutron activity (Ci)

S_R = macroscopic removal cross section for fast neutrons (1/cm)

t = shield thickness (cm)

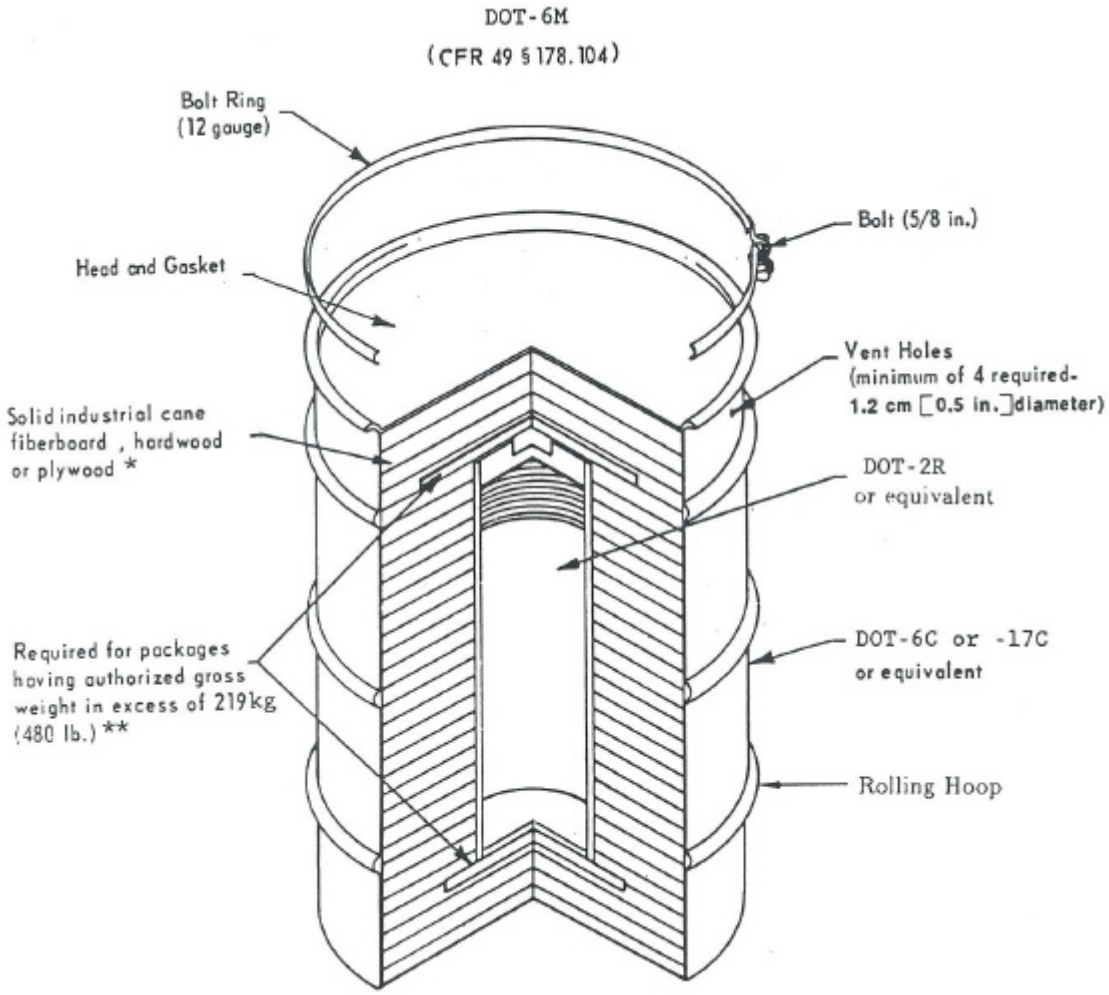
R = radial position

Equation J.4-1 is appropriate for mono-energetic particles. As indicated above, neutron shielding calculations should be performed with a radiation transport code that could model the entire energy spectrum (i.e., fast, epi-thermal, and thermal neutrons). When using the point kernel method for fast neutrons, it is best to model the fast and thermal neutrons (generated by scattering of fast neutrons) separately. The attenuation would then be modeled with the use of transport cross sections. Unfortunately, readily usable neutron cross sections are only available for thermal mono-energetic (2200 m/s, one-speed) neutron. Since fast (high-energy) neutron cross sections tend to be less than thermal (low-energy) neutron cross sections, this unique application of cross-sections should result in an over-estimation of the self-shielding. This in return, results in an over-estimation of the permissible radioactive payload. Thus, these calculations are used to identify an absolute upper bound for the payload. This form of the Point Kernel equation is used in Section J.5 only for purposes of scoping-out the range of possible shielding capability of the 6M containers.

J.5 55-GALLON 6M CONTAINER ANALYSIS

The 55-gallon version of the 6M container shown in Figure J.5-1, was analyzed for its neutron shielding capabilities with and without additional shielding material. This analysis was performed using the code: NEUTRON01.for that is listed in Appendix A of Sanchez 2001. This code uses dimensions for a small and large 2R pipe container within the 6M container. Dimensions were taken from Edling 1975, and are used internally in Stage 5 of the computer code. As can be seen from Stages 5 and 6 of the code (and its output listed in Appendix B of Sanchez 2001), the geometry is broken into six regions – 1) small neutron source, 2) supplemental shielding (within the 2R), 3) the 2R container itself, 4) Celotex® insulation/impact limiting material, and 5) the 55-gallon drum itself. In total 24 different combinations of added internal shielding material and allowed credit for 6M materials were modeled. NEUTRON01 uses the Point Kernel Equation J.4-1 to model the radiation attenuation (upper payload estimates only). Key results from the output listed in Appendix B of Sanchez 2001 are presented in Figure J.5-2 for the most ideal cases – 1) shielding credit for 6M materials and 2) shielding credit for 6M materials plus added depleted uranium shielding material within the 2R. Unfortunately, the results indicate that attenuation of neutrons is small and the major contributor to neutron radiation reduction is due mostly to geometrical spread. From Figure J.5-2 it can be seen that only very small sources, < 2 mCi, might be able to be transported in an unmodified 6M container. This payload corresponds only to the surface dose rate criteria (not the 2 and 5 meter criteria (see Section J.2).

From the results it is apparent the proper shielding techniques for neutron sources would require that two container modifications are needed – 1) sufficient moderator material (low-Z scattering elements) are used close to the neutron source and 2) thermal neutron poisons are incorporated in or around the moderator material. The first modification would be used to scatter neutrons; this would convert fast neutrons into thermal neutrons (i.e., remove fast neutrons from the system). The second modification would efficiently remove thermal neutrons from the system.



* Current design uses Celotex® material (high density).

** Steel-bearing plates.

Figure J.5-1. Geometry of 6M containers (taken from Ref. Edling 1975).

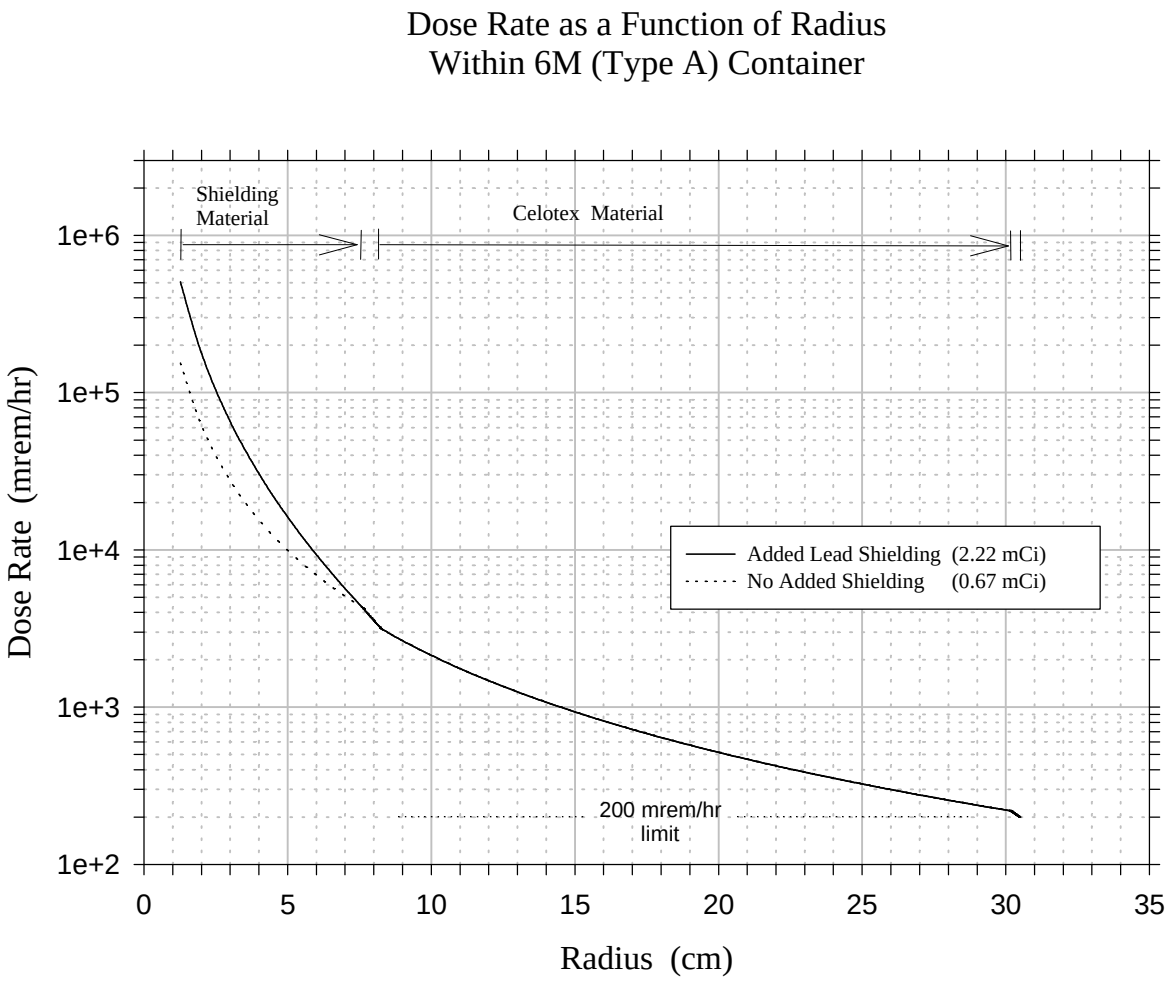


Figure J.5-2. 6M container surface dose rate as a function of container radius. Activity calculated using neutron shielding equations from Section J.4 (see Appendix A of Sanchez 2001 for calculations).

J.6 HYPOTHETICAL ENLARGED S100 TYPE CONTAINER ANALYSIS

As seen in Section J.5, only very small neutron sources can be used in 6M type of containers (simple containers without specially designed neutron absorbers). Larger neutron sources would best be transported with the new S100 pipe overpack (see Figure J.6-1). Currently the S100 container is being analyzed and developed by Los Alamos National Laboratory (LANL) for the transport of small neutron sources (TRAMPAC 2000). The S100 is a 55-gallon 6M type container that uses boronated Water-Extended Polyester/polyethylene composite (WEP) for neutron shielding material (Oliver 1970, TRAMPAC 2000). Fortunately, the neutron shielding analysis performed on the S100 by LANL used the non-analog Monte Carlo code MCNP and was very through. The results indicated two significant findings – 1) the maximum neutron payload is 28 Ci and 2) the surface dose rate was dominated by only neutrons (i.e., secondary gamma due to (n,γ) reactions are insignificant). The 28 Ci payload envelope of the S100 container is significantly large enough to handle most neutron sources in the NISS inventory. For those sources greater than the 28 Ci, a larger container (greater than 55-gallon) would need to be used.

This section analyzes the shielding capacity that would results if a larger diameter S100 type container were to be used. Fortunately, the WEP material in the S100 has significant thermal neutron removal capabilities due to the added boron (a very strong thermal neutron poison). Thus, only the fast component of the neutron flux needs to be modeled. This can be done with use of the Point Kernel approximation again. Furthermore, since the LANL calculations were performed for a 55-gallon geometry, their results could be "extrapolated" to larger diameters by identifying the "scaling-law" for the Point Kernel model. This is done in Equations J.6-1 and J.6-2 below:

$$\frac{f_0}{f_1} = \frac{A_0}{A_1} = \left(\frac{r_0}{r_1}\right)^2 e^{\frac{-\ln(2)(r_1-r_2)}{t_{½}}} \qquad \text{[Eq. J.6-1]}$$

$$A_1 = A_0\left[\left(\frac{r_0}{r_1}\right)^2 e^{\frac{-\ln(2)(r_1-r_2)}{t_{½}}}\right]^{-1} \qquad \text{[Eq. J.6-2]}$$

where

f_0 = initial neutron flux at radius r_0 (n/cm^2-s)
f_1 = neutron flux at radius r_1 (n/cm^2-s)
A_0 = payload activity for shielding material of radius r_0 (Ci)
A_1 = payload activity for shielding material of radius r_1 (Ci)
{= 28 Ci for 55-gal S100 pipe overpack}
r = radius (cm)
{outer radius =30.48cm for 55-gal S100, Refs. TRAMPAC 2000, Edling 1975}
$t_{½}$ = half-layer thickness (cm)
{~ 6 cm, by estimation, for WEP material, see Table J.6-1}

Equations J.6-1 and J.6-2 are slightly different from equations presented in Section J.4, in that they use the half-layer thickness instead of the removal cross section in the attenuation factor. These terms are related, i.e., one could be derived from the other. The half-layer thickness is used here since published values were readily available in Schleien 1998 (see Table J.6-1). Using these values and Equation J.6-2, the neutron shielding-law was used to generate the results listed in Table J.6-2 and plotted in Figure J.6-2.

From these results it can be seen that if the S100 pipe ovepack geometry were to be expanded to a 100-gallon geometry (or place a 55-gallon container within a 100-gallon overpack and fill the voids with WEP material), then a payload of up to 130 Ci is possible.

Table J.6-1. Half-Layer Thickness of Materials for Neutrons from Po/Be Sources [(a)]

Material	Half-Thickness (cm)	Material	Half-Thickness (cm)
Paraffin	6.6	Steel (cold roll)	4.9
Water	5.4	Lead	6.8
12% Borax in Water	5.3	Aluminum	7.8
Brass	4.9		

(a) Data taken from Schleien 1998.

Table J.6-2. Extrapolated Neutron Shielding Results for S100 Type Container [(a)]

Outer Radius (cm)	Payload Activity (Ci)	Outer Radius (cm)	Half-Thickness (cm)
30.48	28	40	144
32	36.8	42	201
34	52.3	44	278
36	73.9	46	383
38	104	47	449
39.37	130		

(a) Data calculated using Equation J.6-2 and data in Table J.6-1. Results presented in Figure J.6-2.

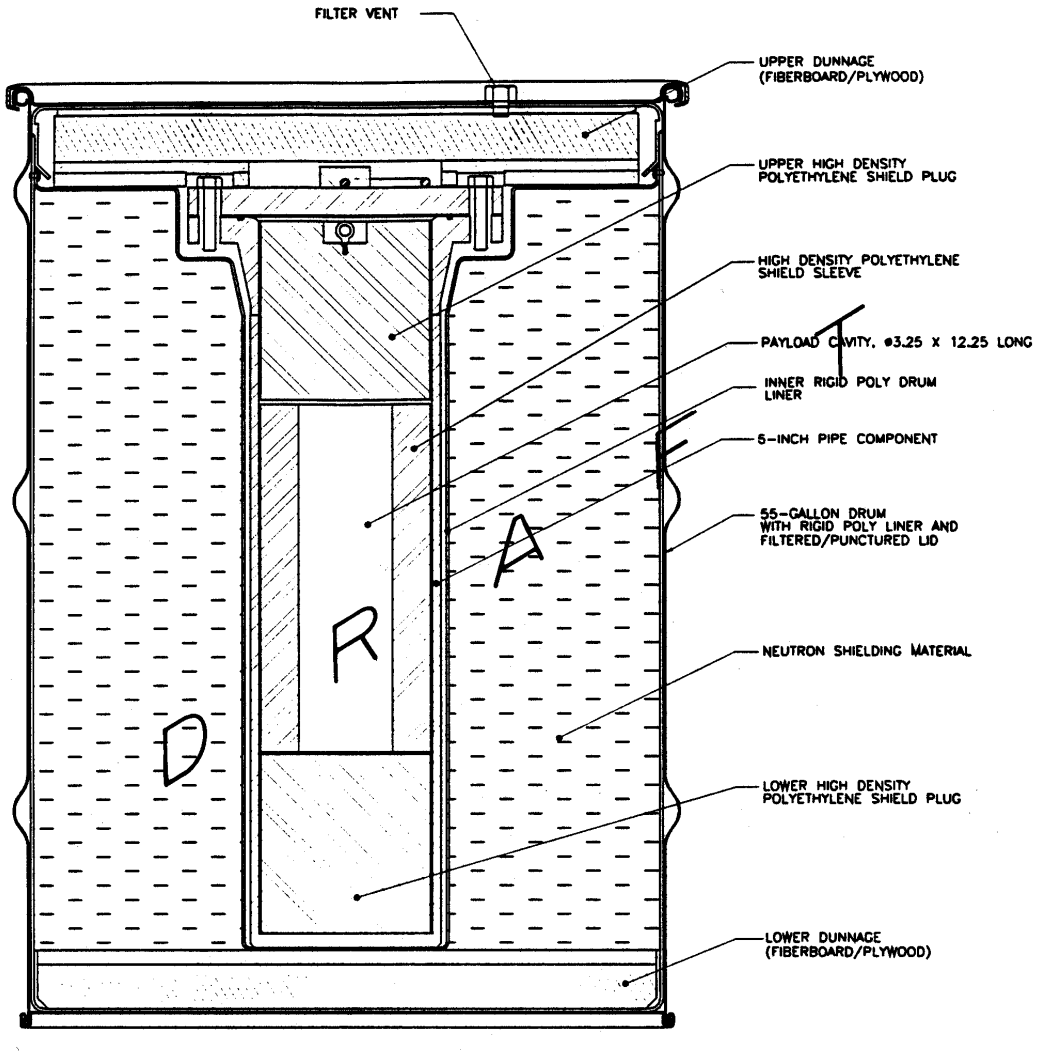


Figure J.6-1. Schematic drawing of S100 Pipe Overpack (drawing taken from Ref. TRAMPC 2001).

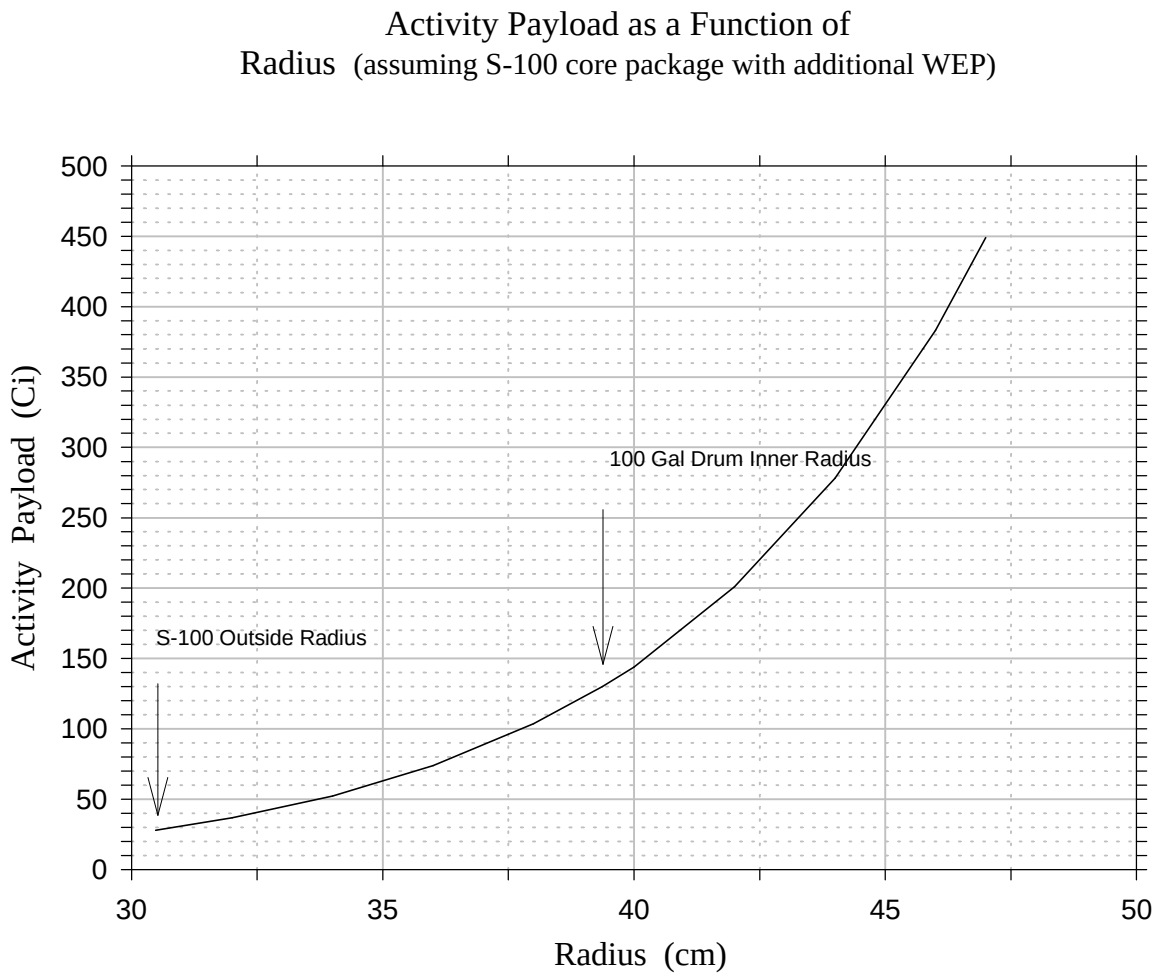


Figure J.6-2. Maximum neutron activity payload as a function of container radius. Activity calculated using neutron shielding scaling-law identified in Equation J.6-2 (see Table J.6-2 for calculations).

J.7 CONCLUSIONS

The simplified neutron shielding calculations performed as part of this study indicated that only very small neutron sources (< 0.002 Ci) could be transported within existing containers (15-, 30-, 55-gallon packages) that do not have exotic neutron moderating/absorption materials. Larger neutron sources up to 28 Ci could be transported in the S100 pipe overpack that is being developed by LANL. If the design of the S100 were to be expanded to a 100-gallon design (see Figure J.7-1), then up to 130 Ci could be transported. Further extrapolation to the diameter size of a Standard Waste Box (SWB, see Figure J.7-2) could open the transport payload to approximately 7,900 Ci (see Table J.7-1 for tabulated results).

Table J.7-1. Overall Shielding Results from Neutron Shielding Study [(a)]

Hypothetical Container	Container Outer Radius		Activity Payload (Ci)
	(inch)	(cm)	
6M	12.	30.48	0.00067
6M with DU Shielding	12.	30.48	0.00222
S100	12.	30.48	28
100-Gallon	15.5	39.37	130
SWB	27.	~ 68.58	> 8,000

(a) Data calculated using Point Kernel method. Dimension taken from Figures J.5-1, J.6-1, J.7-1, and J.7-2.

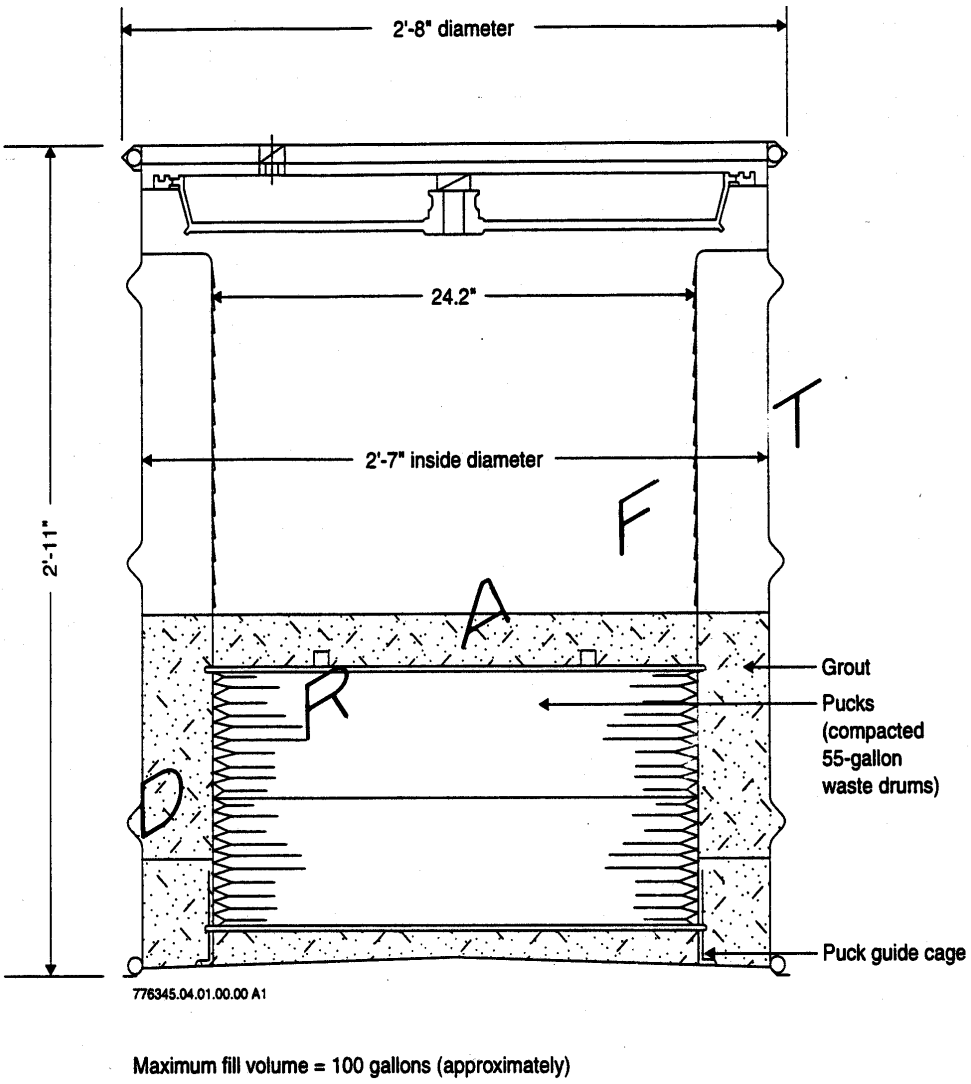


Figure J.7-1. Schematic drawing of 100-gallon drum (drawing taken from draft Ref. TRAMPC 2001).

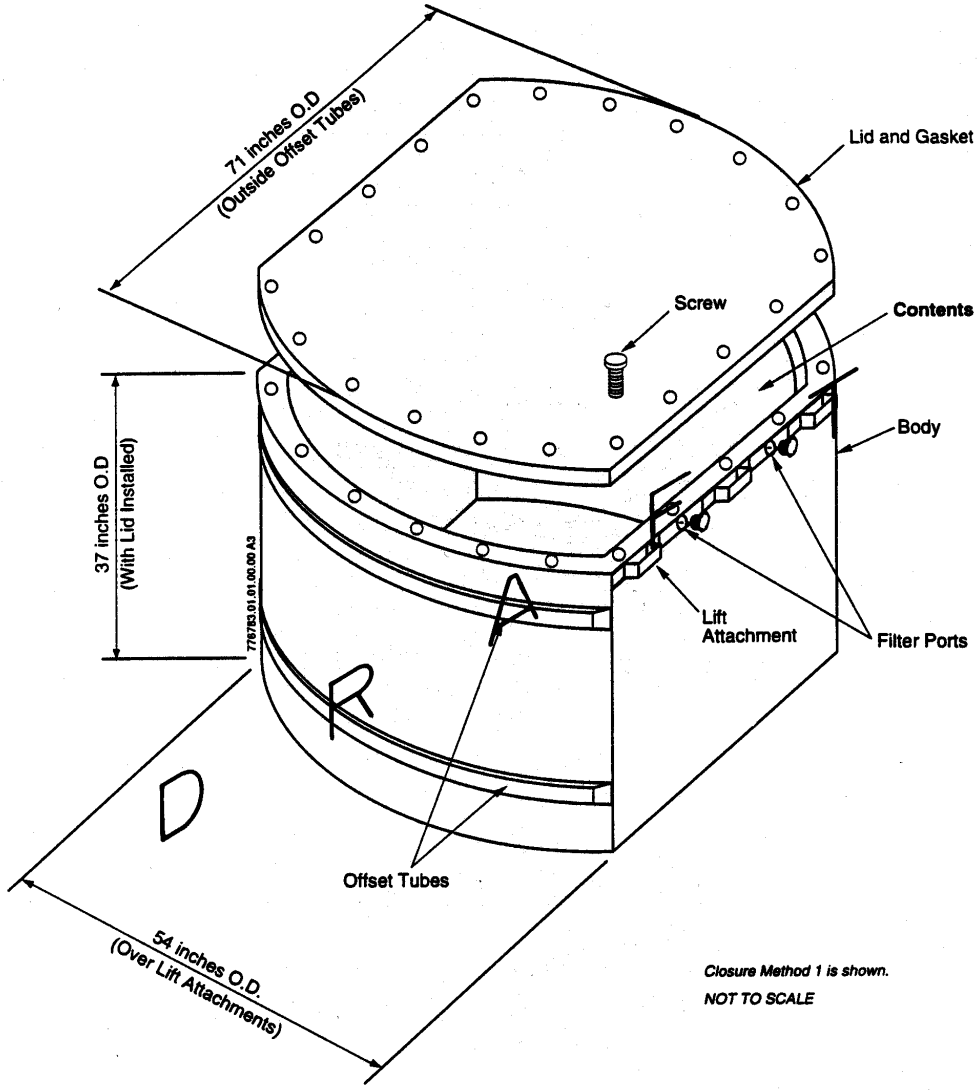


Figure J.7-2. Schematic drawing of Standard Waste Box (drawing taken from draft Ref. TRAMPC 2001).

J.8 REFERENCES

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[Schaeffer 1973] Schaeffer, N.M. (Editor); **Reactor Shielding for Nuclear Engineers**; U.S. Atomic Energy Commission (UC-80), 1973, TID-25951, ISBN 0-87079-004-8, LCCCN 73-600001. (Caution, there are some mistakes in this textbook.)

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Appendix K

DECISION ANALYSIS

As part of this work, a programmatic decision analysis was performed to evaluate several alternatives for dispositioning the Special Need items for which none of the disposition paths described above are appropriate. Those sources remaining at Step 7 of the methodology include non-defense TRU sources (and defense-related, non-TRU sources) that cannot be accepted at WIPP and for which there are no reuse options, have too large an activity to be disposed of as LLW, or are unacceptable to OSRP. In effect, this includes the small fraction of sources in the inventory having an activity greater than 28 curies. Sensitivity of the results of the decision analysis is described in Appendix L.

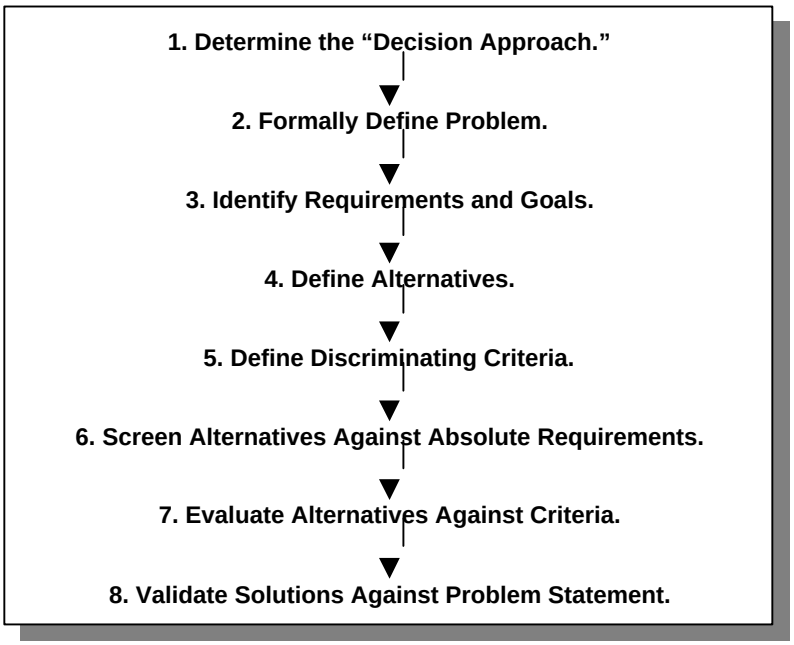


Figure 5-1. Decision Analysis Methodology Steps.

The decision methodology, selection of evaluation criteria, and scoring method used in this trade study are based on standards sources of decision methodologies, including A *Guidebook for Decision Support Methods* [DOE, 2001]. An application of these standard methodologies (See Figure K-1) was developed to support the implementation of decision analysis methods for the Integrated Nuclear Materials Management (INMM) Program.

Problem Statement:

Provide permanent disposition paths for excess DOE neutron sources having no clear disposition path and qualitatively evaluate if there is a significant preference among alternative paths for these sources.

Requirements and Goals:

No formal regulatory or DOE requirements or specific drivers apply to this evaluation. Five goals were established for this study to allow discrimination between alternatives: 1) maximize the disposition of material, 2) maximize use of technically feasible processes, 3) minimize ES&H impacts, 4) minimize cost, and 5) maximize schedule compatibility.

Alternatives for Special Needs Material

- Distributed Storage
- Consolidated Storage
- Processing for Disposal
- Direct Disposal

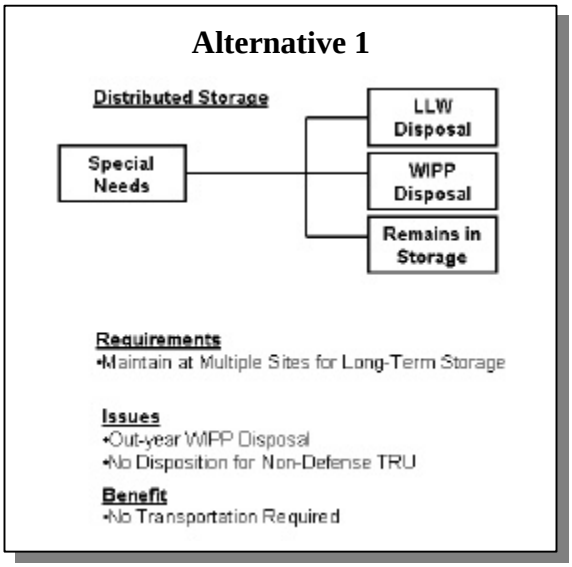
Alternatives Development:

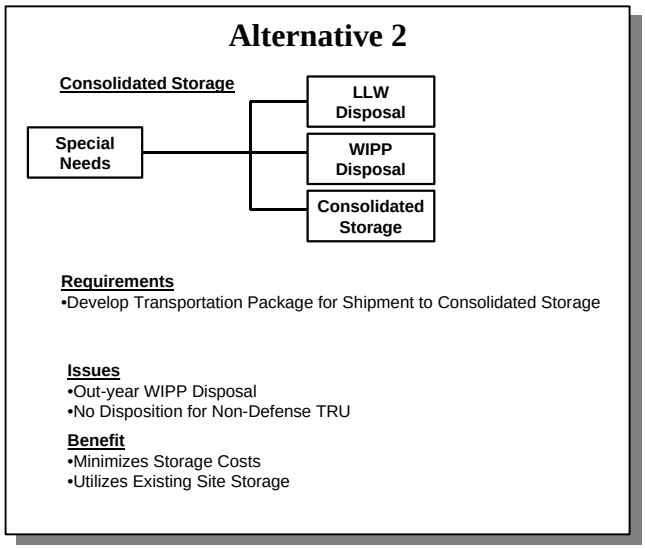
The neutron source disposition path presents reuse and disposal options for a number of neutron sources. Those items that reach Step 7 of the methodology (See Section 4.0 of main text.) are designated as "Special Needs" material and require additional analysis prior to disposition. Four alternatives were identified for evaluation:

The analysis is limited to the small fraction of sources in the inventory containing activities greater than 28 curies, which assumes that the remaining sources can be dispositioned through reuse, disposal as LLW, or as TRU waste at WIPP.

5. Distributed Storage (Baseline)

This alternative assumes continued maintenance and storage of these sources and defers permanent disposition decisions. This alternative does not address concerns related to processing, reuse, transportation, or disposal. This alternative represents the current baseline situation and is included for comparison in the decision analysis against other potential disposition alternatives.



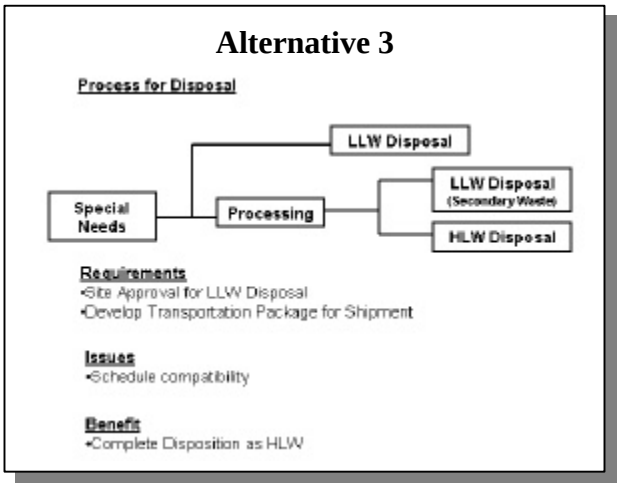


6. Consolidated Storage

This alternative transports all excess sources to a single consolidation location for long-term storage, pending resolution of disposal issues or potential reuse. All excess sources are packaged and shipped to a single location selected for long-term storage, transferring responsibility for the material to the selected consolidated storage site pending resolution of disposal or reuse issues. Transportation and storage considerations apply to this alternative. An advantage of this alternative over distributed storage is that it minimizes the potential for future improper disposal incidents. What happens to the material after receipt by the selected consolidated storage site (long-term storage, reuse, disposal) is not treated in consideration of this alternative by the decision analysis.

7. Processing for Disposal

A small fraction of the >28 Ci sources are not "defense-related" and cannot be disposed of as TRU waste at WIPP. Chemical processing provides a disposal solution for most of these sources by mixing the radionuclides into HLW streams for eventual disposal at a deep geologic repository. (Note that a small number of the non-defense sources may not be suitable for such processing, but are a negligible fraction of the complex's overall non-defense inventory.) Processing for disposal resolves a key issue for non-defense TRU material. The neutron sources would be transported to a single processing facility at Argonne National Laboratory-West (ANL-W) or

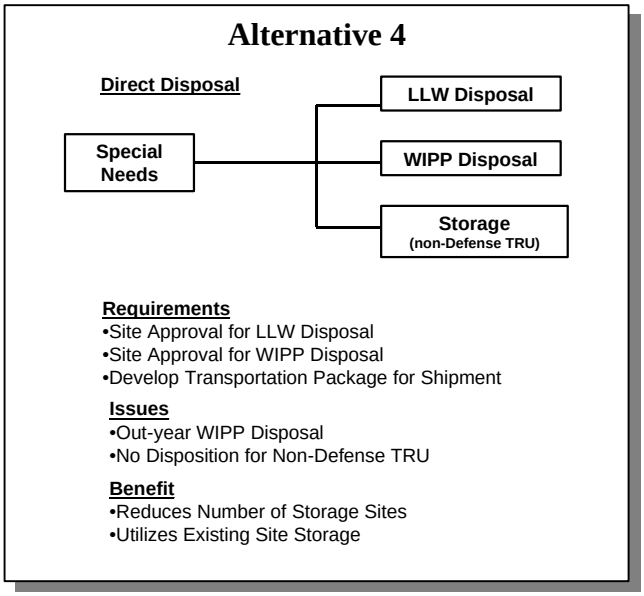


the Savannah River Technology Center (SRTC). The specific facility would be selected after a more detailed review of capabilities and infrastructure upgrades required. Under this alternative, the material is separated and processed into HLW, for ultimate disposal at a HLW repository. Note that this alternative involves the need to transport the sources to a processing facility, but currently there are no transportation containers available for this purpose. The problem of the lack of available transportation packaging also applies to the Consolidated Storage and Direct Disposal alternatives.

Two separate processing options were considered in defining this alternative. One option is the development of an electrometallurgical process at ANL-W. This option, described in more detail in Appendix M, uses the Hot Fuel Dissolution Apparatus (HFDA) in the Hot Fuel Examination Facility (HFEF) to convert PuO_2/Be sources into two waste streams, with the PuO_2 converted to $PuCl_3$ in a ceramic waste form, and the Be converted into a Be/U product through an electrorefining process. Some additional equipment would be needed to prepare the sources for processing, and there is some uncertainty in the process methodology. No additional shielding is anticipated as necessary and incremental waste would not be generated by this process.

The second option (described in more detail in Appendix N) is a chemical or physical separation and repackaging process in the High-Level Cells (HLC) facility at the SRTC. Additional shielding would be needed for the processing facility, and there is some minor uncertainty in the chemical processing option. No NEPA modifications are considered likely.

These processes were developed for treatment of the larger (>28 Ci) sources and assumes the smaller sources would be disposed of through other defined disposition paths. Cost and schedule estimates for these processes range from $750K to $2.48M with an operational period of 2-4 years. Either option could account for most, and perhaps all, of the ^{238}Pu and ^{241}Am sources. As is true of all but the Distributed Storage alternative, this alternative must address transportation concerns for shipment of the various sources to a processing facility. Post-processing considerations such as waste packaging, transportation, and disposal or reuse are not included in the decision analysis for this alternative.



8. Direct Disposal

The fourth alternative recognizes that the long-term solution for all of these excess neutron sources is disposal. Possible disposal options include LLW disposal for some sources or disposal as TRU at WIPP. Direct disposal involves packaging and shipping the inventory to a disposal site and ensuring satisfaction of the Waste Acceptance Criteria for the disposal site. This alternative does not include consideration of processing or reuse options.

This alternative therefore assumes licensing of the Standard Waste Box with additional shielding for transporting these sources and a disposition path only for defense-related TRU waste that can be accepted at WIPP (i.e., there is no disposition path for "non-defense" items, in particular, those that can't be disposed of as LLW).

Discriminating Criteria:

Criteria were developed for use in discriminating among alternatives their ability to meet the established goals. The discriminating criteria defined for this study include:

1. Dispositioned Inventory
2. Complexity
3. Flexibility
4. Transportation Availability
5. Dose Potential
6. Facility Cost
7. Processing Cost
8. Schedule Compatibility

A more detailed definition and description of the criteria is provided in the discussion of results below. The five goals were first qualitatively weighted by their perceived importance to the decision. By consensus of the decision team, it was determined that the goal of maximizing the disposition of the inventory was of greatest importance, followed closely in importance by the goals of technical feasibility and schedule compatibility. Cost and safety considerations were not considered as important for the purposes of this decision. (Note, however, that it is assumed all activities are conducted in a safe and compliant manner.) Consequently, qualitative weightings of 30%, 20%, 15%, 15%, and 20% were assigned to the five goals.

The eight criteria were then allocated among the five defined goals. For the two goals assigned more than one discriminating criteria, the criteria were then weighted by their perceived importance relative to that goal. For the technical feasibility goal, for example, transportation availability was weighted somewhat greater than the criteria of process complexibility and flexibility. Similarly, the facility costs (capital improvements) criterion was weighted slightly less than processing costs with respect to the goal of minimizing cost. The normalized weights for the eight criteria are shown in Table K-1.

Table K-1. Weighting of Decision Criteria

Goal	Criteria	Normalized Weight
Maximize Material Disposition (30%)	Dispositioned Inventory (100%)	0.30
Maximize Technical Feasibility (20%)	Process Complexity (40%)	0.08
	Process Flexibility (30%)	0.06
	Transportation Availability (30%)	0.06
Minimize ES&H Impacts (15%)	Dose Potential (100%)	0.15
Minimize Cost (15%)	Facility Costs (40%)	0.06
	Processing Costs (60%)	0.09
Schedule Compatibility (20%)	Schedule Compatibility (100%)	0.20

Scoring and Results

For each alternative, a score was assigned to each of the criteria by the decision team, using a scoring range of 1 (worst/bad) to 10 (best/good), although use of the full range for any criterion was not required (see Table K-2). The score for alternative "i" is then given by the formula:

$$S_i = \sum_{j=1}^{8} k_j u_{ij} = \sum_{j=1}^{8} k_j \left(\frac{\left(S_{ij} - S_{\min}\right)}{\left(S_{\max} - S_{\min}\right)} \right) \text{ for i = 1, 2, 3, 4}$$

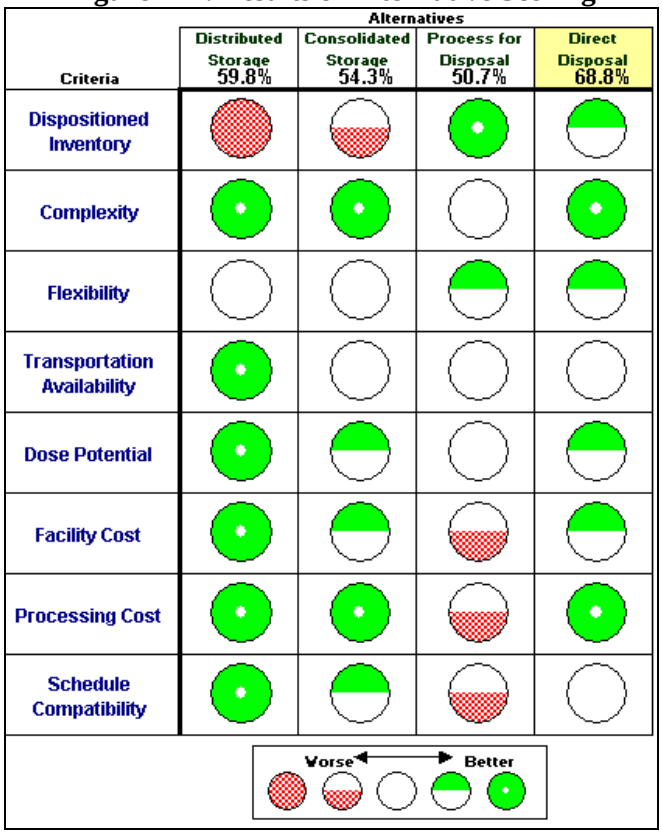
where S_{min} and S_{max} represent the minimum and maximum scores (in this case, 1 and 10), respectively, k_j is the normalized criteria weight for criterion "j", and S_{ij} is the score given to criterion "j" for alternative

"i." The scores (averaged over individual scores assigned by each of the several members of the decision team) are shown in Table J-2, and in the schematic “Consumer Reports” chart of Figure K-2.

Table K-2. Alternative Scores

Scoring Criteria	Weight (k_i)	Alternative Criteria Scores (S_{ij}) [Scoring range: 1 (Worst) to 10 (Best)] 1 Distributed Storage	2 Consolidated Storage	3 Process For Disposal	4 Direct Disposal
Dispositioned Inventory	0.30	1.00	2.83	8.33	7.00
Complexity	0.08	9.17	8.33	5.67	8.33
Flexibility	0.06	5.33	6.17	6.67	6.83
Transportation Availability	0.06	9.67	5.83	5.83	5.83
Dose Potential	0.15	8.67	7.50	4.67	8.17
Facility Cost	0.06	9.00	6.50	3.00	7.00
Processing Cost	0.09	9.33	8.50	3.50	8.33
Schedule Compatibility	0.20	8.83	6.83	3.33	6.33
Total Alternative Score*, S_i, (%)		59.8%	54.3%	50.7%	68.8%

Figure K-2. Results of Alternative Scoring



Results indicated a clear preference for the Direct Disposal alternative. Somewhat less preferable were the Distributed Storage and Consolidated Storage alternatives. Least preferable was the Process for Disposal alternative.

Ranked Alternatives

Rank	Alternative	Score
1st	Direct Disposal	68.8%
2nd	Distributed Storage	59.8%
3rd	Consolidated Storage	54.3%
4th	Process for Disposal	50.7%

Direct Disposal was identified as the alternative that could provide final disposition for nearly the entire inventory. Only a few large, non-defense related sources (a minor component of the non-defense inventory across the complex) would be excluded. This alternative shares similar transportation and packaging issues with the less preferable Consolidated Storage alternative, achieves disposition for a large fraction of the inventory unlike the Distributed Storage alternative, and shares similar cost and safety considerations with both of these alternatives. The Process for Disposal alternative scored lower in most areas, but does have the ability to process the entire inventory by combining the material with a HLW stream for eventual disposal at a HLW repository.

Discussion of Discriminating Criteria and Scoring Results

CRITERION	DISCUSSION
Dispositioned inventory (30%)	Because one of the goals is to maximize disposition of material, this criterion addresses the ability of an alternative to disposition as much of the inventory as possible, taking into consideration the various types of sources of differing isotopic composition and activity, dimensional and construction considerations, and varied locations. Higher scores are assigned to alternatives that are qualitatively understood to be capable of dispositioning the largest fraction of the inventory. Variations in scoring may appear if, for example, one alternative can disposition the majority of curie content, but for some reason could not handle the vast majority of items for other isotopes. Discussion rationales indicated that the current baseline of distributed storage does not result in disposition of any sources and hence scored poorly, with little perceived improvement in consolidated storage. Processing for disposal or direct disposal scored highly, since these options would result in the ability to dispose of most or all of the excess inventory.
Complexity (8%)	This criterion is used to rank alternatives on the complexity of processing involved, and includes such areas as technology maturity and availability, process uncertainty, and relative complexity. Proven, available technology of low complexity and uncertainty is given a higher score than more complex or unproven technology. As indicated by the scoring, storage and disposal alternatives scored highest on this criterion, with the existing system of distributed storage scoring highest. Not surprisingly, the processing for disposal alternative scored somewhat lower on this criterion.

CRITERION	DISCUSSION
Flexibility (6%)	This criterion addresses differences among the alternatives in their ability to provide multiple potential paths for disposal or reuse of the various sources; those with a greater degree of freedom ranked higher. Longer-term storage options, for example, allow decisions to be made for reprocessing certain sources into more useful forms, allow time for potential users to be identified, and permit delaying decisions regarding final disposal. Processing and disposal alternatives, however, are likely to receive lower scores because they eliminate options other than disposal once the sources are processed or disposed. The overall results gave lower scores to storage alternatives and the highest score to direct disposal. It appears the higher scores assigned to the processing and disposal alternatives reflects a consideration that pursuing either of these options may take a long time and allow additional opportunity for other options. Despite wide variations in scoring for this criterion, overall, it contributes only 6% to the final score for each alternative and does not seem to be a significant discriminator.
Transportation Availability (6%)	This criterion was used to discriminate among alternatives on the basis of transportation issues that may exist to favor one alternative over another. The existing distributed storage system does not involve transportation and thus received a very high score. The other three alternatives shared a common set of transportation issues, such as lack of availability of adequately shielded licensed packaging and dimensional constraints of existing packaging.
Dose Potential (15%)	Although it is assumed that all operations are carried out in a safe and compliant manner for all of the alternatives, some alternatives involve inherently less safe operations and a greater risk for radioactive dose. A criterion for discriminating among alternatives from a safety perspective, qualitatively expressed by the relative dose potential, was therefore established, with alternatives having a lower dose potential assigned the highest score. Not unexpectedly, the lowest score was given to the processing for disposal alternative, which involves opening sealed sources and chemical processing in shielded facilities. Storage and direct disposal alternatives would not necessarily require destroying sealing integrity.
Facility Cost (6%)	One of two criteria defined to discriminate alternatives on the basis of cost, the facility costs criterion is used to compare alternatives for relative differences in the overall cost incurred by the need to construct new or modified facilities to pursue an alternative. Lower cost is assigned a higher score. The highest score was received by the distributed storage alternative, which uses existing storage facilities. The consolidated storage and direct disposal alternatives received slightly lower scores, which is reasonable since they primarily involve existing facilities but may involve minor facility modifications. The lowest score was assigned to the processing alternative, which requires facility modifications to enhance shielding, procurement of additional equipment, and other modifications to enable processing of the neutron sources.

CRITERION	DISCUSSION
Processing Cost (9%)	The second cost discriminator was defined by the operational costs associated with each alternative, again with lower processing costs given a higher score. Although processing or operational costs are associated with all of the alternatives, costs associated with storage and disposal alternatives were judged to be fairly low, involving primarily surveillance and maintenance activities, and therefore given a high score. Processing costs for the disposal processing alternative, however, involves additional operational costs and was assigned a significantly lower score.
Schedule Compatibility (20%)	This criterion evaluates the relative feasibility of different alternatives from a scheduling perspective. Some alternatives are most feasible if pursued during a defined "window of opportunity," or are more constrained by scheduling concerns, while others are insensitive to timing issues. Alternatives without scheduling constraints are preferable and are therefore assigned higher scores. The existing distributed storage system, while it doesn't result in a final disposition for any of the sources, is also free of schedule concerns and therefore received a high score. Schedule compatibility was viewed as slightly more of an issue for the consolidated storage and direct disposal alternatives, and consequently received a lower average score. The disposal processing alternative, however, was viewed as quite sensitive to scheduling issues and therefore given a rather low score.

Advantages and disadvantages of the four alternatives were reviewed during the scoring discussions and are summarized below. The three alternatives of Consolidated Storage, Processing for Disposal, and Direct Disposal are all subject to the major disadvantage that there is currently no packaging licensed for transporting these sources. These sources require more effective shielding than is available in licensed packaging, and dimensions of some of these sources prevent their being contained in those packagings. Resolution of these issues is needed before these materials could be transported to a consolidated storage location, a processing facility, or a disposal site.

The current baseline system of storing excess neutron sources at various sites is the only alternative that does not involve the transportation and disposal issues present for the other three alternatives. The major disadvantage of the Distributed Storage alternative, however, is that it does not result in a final disposition for any of the sources.

The chief advantage of the Consolidated Storage alternative, assuming transportation issues can be resolved, is that it involves well-proven systems, no significant additional cost, and by removing excess sources from various sites, potentially allow closure of other storage facilities. A disadvantage of this alternative is that long-term storage does not result in disposal as a final disposition, and therefore implies long-term ongoing costs.

The Processing for Disposal alternative has a significant advantage over the other alternatives in overcoming disposal issues by virtue of its transforming the material into high-level waste, for which disposition in a HLW repository is a defined disposition path. Disadvantages include the greater complexity, cost, schedule, and safety considerations, as well as the packaging and transportation issue.

Direct Disposal was identified by the decision analysis as the most preferable disposition path of the four alternatives, which is not an overly surprising conclusion. Assuming resolution of the packaging and transportation issue common to three of the alternatives, it results in the final disposition of the majority of the sources, and if a solution is found to permit disposal of the non-defense TRU component, for the entire inventory.

Appendix L

Sensitivity Evaluation of Decision Analysis Results

The decision analysis performed for comparing alternatives for sources for which there are no current disposition paths is described in Section 5.0 of the main report text and Appendix K. Included in this appendix is an evaluation of the sensitivity of the results of that analysis. First is a summary of the range of scoring generated by the decision team in scoring the four alternatives defined for the analysis. Second is a description and discussion of the variability in scoring for each of the eight criteria used to comparatively rank the four alternatives. Third is an examination of the sensitivity of the results to variation in the scoring of the criteria. And, finally, the behavior of the relative ranking of the alternatives to variations in the weighting assigned to the decision criteria is described.

Scoring Ranges

Figure L-1 provides a graphic depiction of the range of scores assigned to each of the four alternatives by the decision team. Alternative 3, Process for Disposal, showed the greatest variation in scoring by the members of the decision team, indicative of differences of opinion regarding weighting of the decision criteria for each alternative. Less variation and a greater degree of consensus on the scoring was observed for the current baseline system of distributed storage.

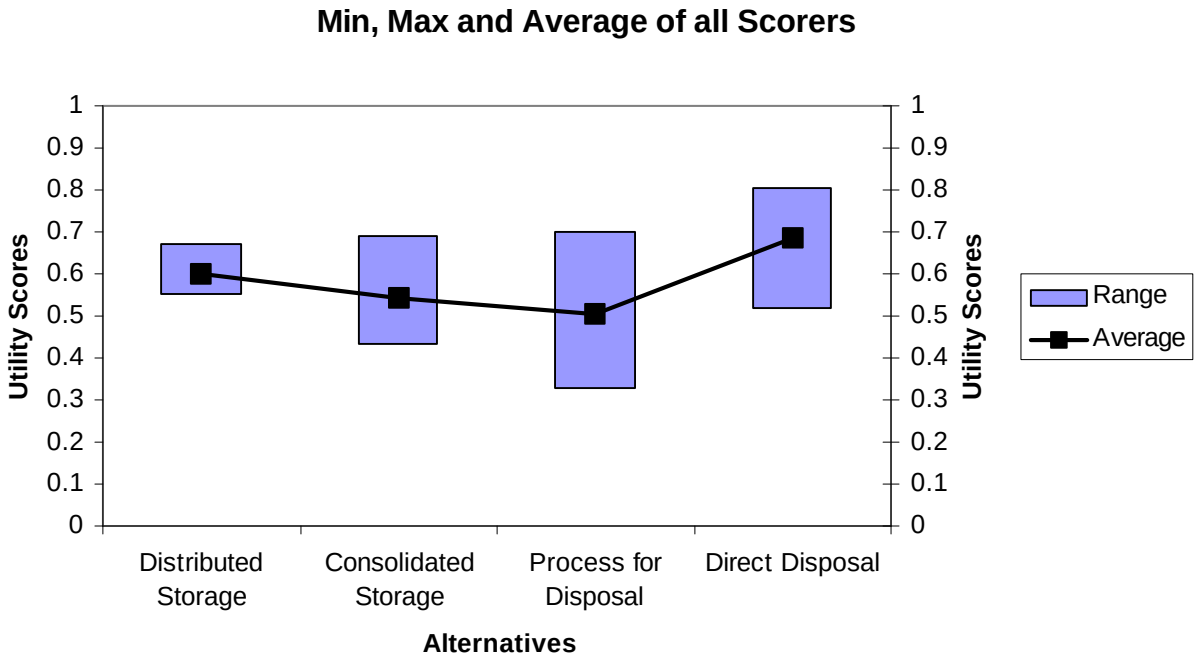


Figure L-1. Scoring Ranges and Averages

Standard Deviation of Alternative Scores by Decision Criteria

Figure L-2 provides a more detailed illustration of the variation in the scores assigned to the four alternatives, by showing the standard deviation of alternative scores for each of the eight decision criteria. The greatest spread among scores was observed for the score assigned to the "Process Flexibility" criterion for the Distributed Storage alternative. This criterion, however, contributes only 6% to the overall scoring, and has no major effect on the results.

A large standard deviation among the decision team scores also was observed for the scoring of the "Processing Capability" criterion (30% of the overall score for each alternative) for the Consolidated

Storage alternative. Despite the large variance, it is noted that the average score agrees with expectations that storage options are worst at dispositioning the inventory, Direct Disposal provides a disposition for a large fraction of the inventory, and that Processing for Disposal provides a disposition for the largest fraction of the inventory. In general, for most of the decision criteria, there was a larger spread in scores for the Process for Disposal alternative than for the other three alternatives. Again, this appears indicative of a wider range of opinion by the decision team members regarding the relative scoring of the four alternatives against the defined criteria.

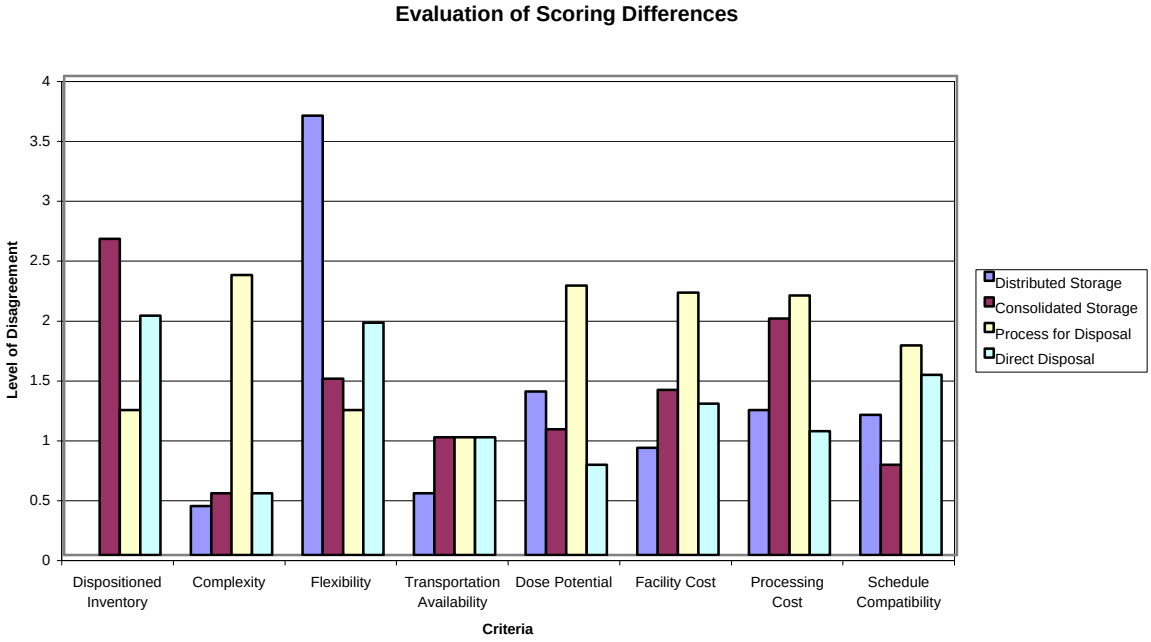


Figure L-2. Standard Deviations of Alternative Scores by Decision Criteria

Score Sensitivity

Figure L-3 illustrates the sensitivity of the relative ranking of preferred alternatives to changes in the overall scores. Varying individual scores by adding or subtracting a value of one (more than 20% of the full range of 1 to 10) shows that the overall results are relatively insensitive to the scores assigned to the decision criteria. The largest effect is again seen for the processing capability criterion, which alone accounts for 30% of the total score. However, even for this substantial variation, Direct Disposal remains the preferred alternative. Some small degree of overlap occurs for several of the criteria among the other alternatives at these extremes, which is not unexpected given the relative similarity in scores assigned to these three alternatives.

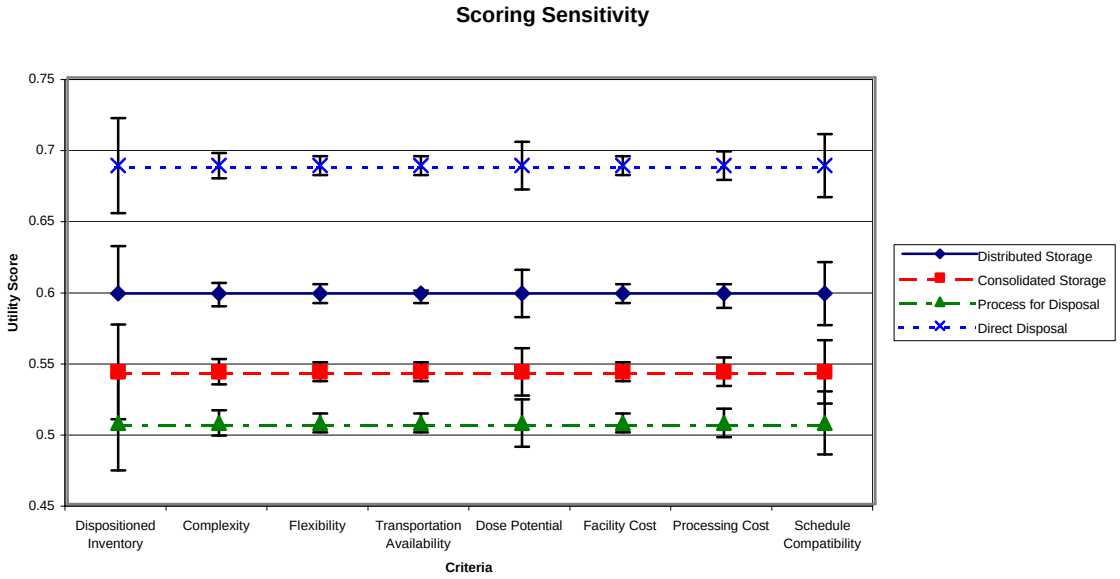


Figure L-3. Sensitivity to Scoring Variation

Discriminating Criteria Sensitivity

Figures L-4 through L-11 illustrate the changes in alternative preferences with variations in the relative weighting assigned to each of the decision criteria.

For the eight graphs for the individual discriminating criteria, note first that at the value assigned to each of the criteria, the score for each alternative matches that shown in the decision analysis table. On each graph, as the weight assigned to that criterion is varied from a 0 (no weight) to 1 (100% of the total score), changes in the relative preferences among the four alternatives are seen.

The most complex behavior is seen in the plots for the **Dispositioned Inventory** criterion. For scoring, a value of 30% was assigned to this criteria, for which Direct Disposal was the most preferred alternative at 68.8%, followed by Distributed Storage at 59.8%, Consolidated Storage at 54.3%, and finally Process for Disposal at 50.7%. If the weighting of this criterion were increased (with consequent decreasing weights for the remaining criteria), Direct Disposal remains preferred unless the weighting increases to more than 70% of the total, at which point Processing for Disposal becomes the preferred alternative. All other things being equal, this is consistent with a recognition that a small fraction of the overall inventory cannot be treated by direct disposal (i.e., the small fraction on non-defense TRU waste); conversely, while the processing alternative may have other drawbacks it can provide a disposition path for the entire inventory and would be the preferred alternative if that were the only consideration of importance to the decision maker. The **Flexibility** criterion showed similar behavior with increasing weighting, with Processing for Disposal increasing in preference as the weight is increased from its initial value of 6%. At very high weightings greater than about 80%, Processing for Disposal becomes more preferable than the Direct Disposal alternative.

The **Transportation Availability** criterion, weighted at 6%, also showed several changes in preference as the criterion weighting was increased. As the weight is increased to about 25%, the Distributed Storage alternative becomes preferable over the Direct Disposal alternative and the Processing for Disposal alternative becomes favored over the Consolidated Storage option. The former transition is consistent with the perception that transportation is not a consideration for the existing distributed storage

system, an effect that comes into play in determining preferences as the importance of this criterion reaches these higher values. For the latter transition, it is noted that these two alternatives received identical scores for this criterion and the result indicates the effect of other factors discriminating between these two alternatives.

Although Distributed Storage remains the most preferred alternative as the weighting is increased to even higher values, at a weighting of about 70%, the Processing for Disposal alternative surpasses the Direct Disposal alternative as the next most preferred alternative.

The **Schedule Compatibility** and **Facility Cost** criteria, which were weighted at 20% and 6%, respectively, showed similar behavior as the criteria weights were increased to larger values. For the former, the Distributed Storage alternative becomes more preferable than the Direct Disposal alternative as the weight increases to more than about 55%. If schedule compatibility was the dominant driver for the decision, scheduling implications for the Direct Disposal alternative would eventually enter into the decision. Similarly, increasing the weighting of the **Facility Cost** criterion from its value of 6% to greater than 50% shows a change in preference from the Direct Disposal alternative to the Distributed Storage alternative.

The results are insensitive to changes in the weighting of the **Complexity**, **Dose Potential**, and **Processing Cost** criteria. This is consistent with the scores that indicate the processing alternative is the least mature technology, has the highest dose potential, and received the lowest scores for processing costs, while the other alternatives all scored high for these criteria.

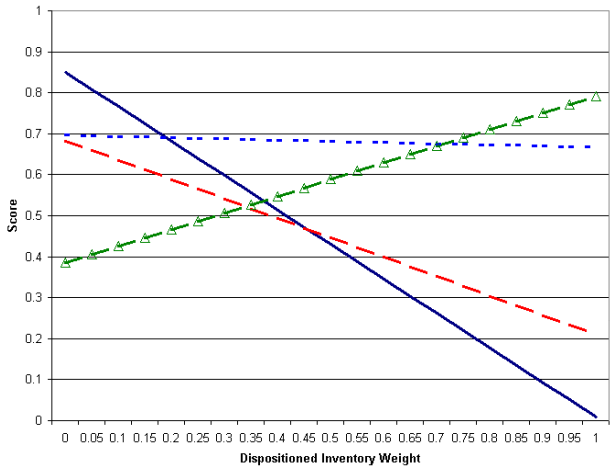


Figure L-4. Dispositioned Inventory

Increasing criterion weight from 30% to more than 70% changes preference from Direct Disposal to Processing for Disposal.

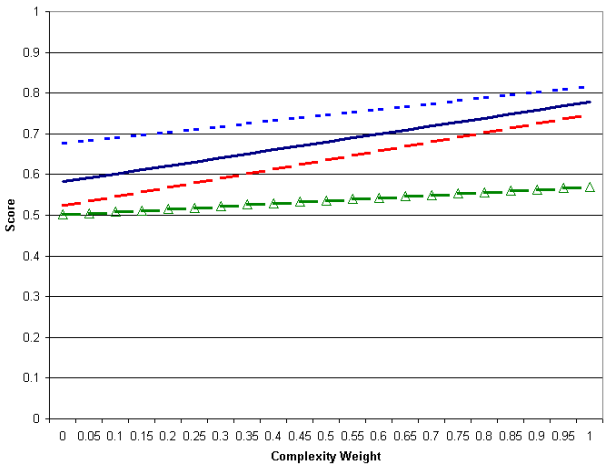


Figure L-5. Complexity

No change in preference as criterion weight is varied from 8%.

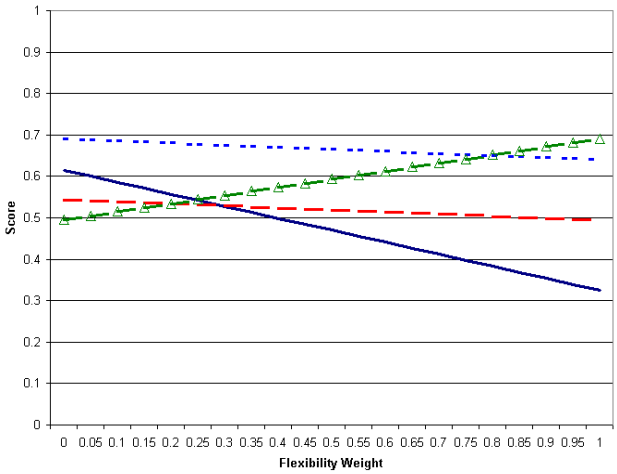


Figure L-6. Flexibility

Increasing criterion weight from 6% to more than 80% changes preference from Direct Disposal to Processing for Disposal.

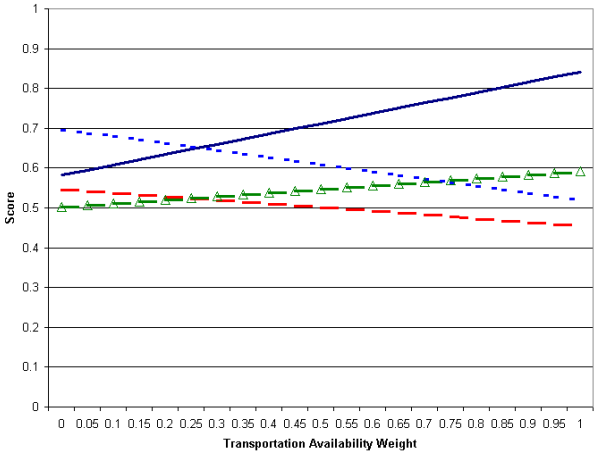
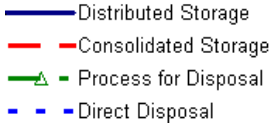


Figure L-7. Transportation Availability

Increasing criterion weight from 6% to more than 25% changes preference from Direct Disposal to Distributed Storage.



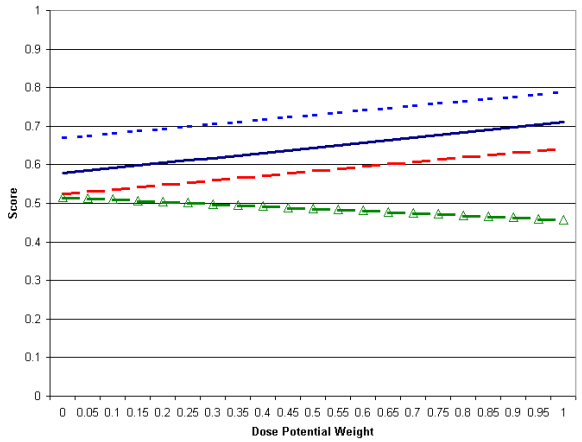


Figure L-8. Dose Potential

No change in preference as criterion weight is varied from 15%.

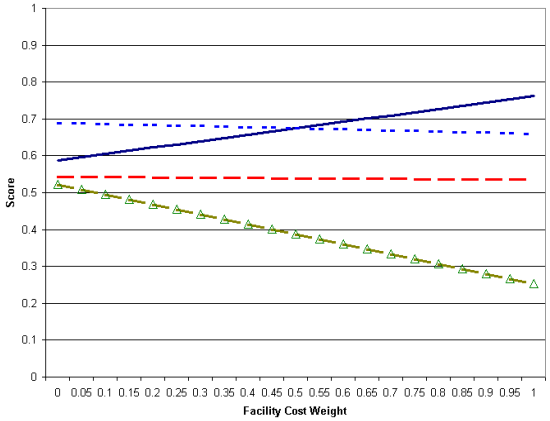


Figure L-9. Facility Cost

Increasing criterion weight from 6% to more than 50% changes preference from Direct Disposal to Distributed Storage.

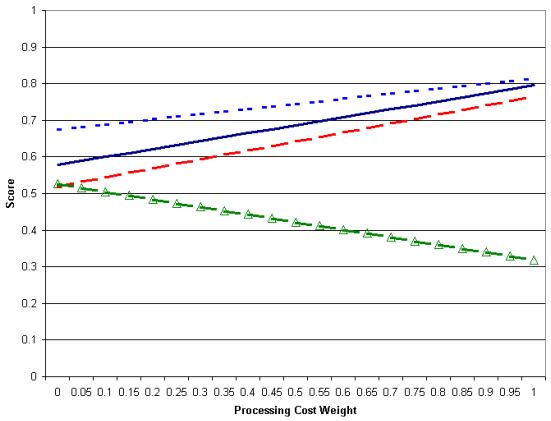


Figure L-10. Processing Cost

No change in preference as criterion weight is varied from 9%.

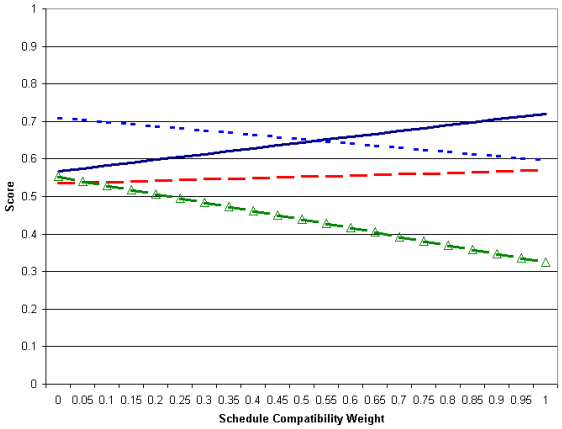
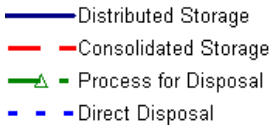


Figure L-11. Schedule Compatibility

Increasing criterion weight from 20% to more than 55% changes preference from Direct Disposal to Distributed Storage**.**



Appendix M

Neutron Source Treatment at ANL-West in the Electrometallurgical Spent Fuel Treatment Process

Contributed by Michael F. Simpson
Argonne National Laboratory-West

Abstract

This is a proposal to develop a process for treating high-activity neutron sources in the electrometallurgical treatment (EMT) process at ANL-West. These sources are comprised primarily of plutonium oxide and beryllium. Since the EMT process is designed to treat metal fuel, an oxide reduction front end step will be needed. It is proposed to use the Hot Fuel Dissolution Apparatus (HFDA) in the Hot Fuel Examination Facility (HFEF) hot cell for oxide reduction. The resulting mixture of salt, metallic plutonium, and beryllium can be fed into one of the EMT process electrorefiners. The plutonium will subsequently partition into the ceramic waste stream. The beryllium will be accumulated in the uranium product stream. There will be no additional waste streams, and the impact on the waste volumes generated by the EBR-II spent fuel treatment process will be negligible.

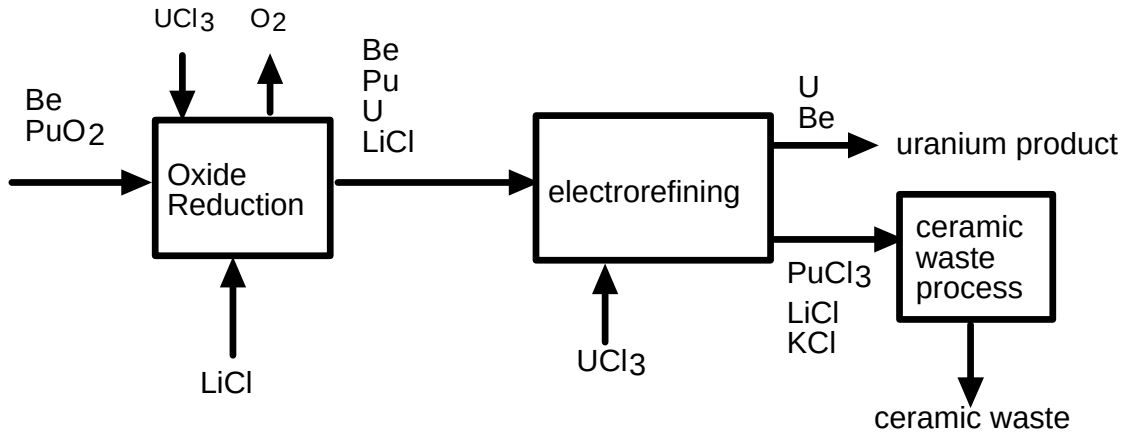
Description of Need

There are approximately 74 neutron sources that have been identified as being unsuitable for direct disposal at the Waste Isolation Pilot Plant (WIPP) due to having activities exceeding 15 curies. Most of these sources are comprised of Pu-238 and Be. However, six of them contain americium, one contains californium, and two are comprised of plutonium fluoride. The technology presented in this proposal is aimed at treating the Pu-238/Be sources. However, it is likely that this same process could be used for the other sources as well. Table I lists 65 sources that are definitely suitable for treatment at ANL-West. Note that this table will be updated as more detailed information on these sources becomes available to ANL-West, including masses and chemical and physical form.

Proposed Treatment Process

A flowsheet for the proposed process to treat Pu-238/Be neutron sources is shown in Figure I. The PuO_2 is first reduced to Pu metal and is then electrochemically oxidized to $PuCl_3$. The plutonium chloride is eventually disposed of in a ceramic waste form. It is believed that the beryllium will partition into the uranium product from the EMT process. If this process proves to also be suitable for americium sources, the Am would also be stabilized in the ceramic waste form.

Figure I. Overall view of the proposed neutron source treatment process.



Before entering into this process, the neutron sources will need to be cut open to expose the plutonium and beryllium/lithium material. Specialized equipment may need to be designed for this purpose. But it is likely that the sources can be cut manually using something akin to a tubing cutter. This work can be done in the argon-atmosphere hot cell in the Hot Fuel Examination Facility (HFEF) at ANL-West.

The oxide reduction process will use an existing test reactor called the Hot Fuel Dissolution Apparatus (HFDA). It is installed in the Hot Fuel Examination Facility (HFEF) and has been used for laboratory-scale electrorefining and ion exchange experiments. It has a capacity of approximately 750 ml of molten salt with a maximum Pu loading of 225 grams. Though the HFDA will need some minor modifications in order to serve as an oxide reduction reactor, it is a functioning piece of equipment at this time. It is installed in the hot cell and has operational heaters and stirring motors. Non-oxide sources may skip the oxide reduction process and proceed directly into the electrorefiner.

Neutron shielding calculations have been performed for both the HFEF hot cell walls and viewing windows. These indicate dose rates of 0.1 mrem/hr through the walls and 0.5 mrem/hr through the windows.

After treating a number of neutron sources, the mixture of salt, Pu metal, and Be metal can all be fed into an electrorefiner in the Fuel Cycle Facility (FCF). The molten salt used in the oxide reduction process as well as the plutonium will partition into the electrorefiner's molten LiCl-KCl salt phase. The beryllium is expected to deposit along with uranium from spent fuel on the electrorefiner's cathode, but alternatively it may remain in the anode basket or become stabilized in the salt at $BeCl_2$. If it does deposit with the uranium on the cathode, the net amount of beryllium added to the uranium product stream is expected to be very small compared to the total mass of this waste stream. If sixty sources are treated with 50 grams of Be each on average, 3 kg of Be will be mixed with over 30 MT of uranium product. It would similarly have a negligible impact on the process if it remains in the anode basket or partitions into the salt. The salt from the electrorefiner is eventually fed into a ceramic waste process. If each source has an average of 1 g of Pu-238, the mass of Pu-238 in the ceramic waste stream would increase from about 34

grams to 96 grams. However, the total ceramic waste stream is expected to be 51 MT from the processing of EBR-II and FFTF spent fuel. It is, thus, not expected that the increased Pu-238 loading will be a significant problem.

This disposal plan results in virtually zero incremental waste. All of the neutron source constituents are incorporated into existing waste streams coming out of the treatment of the EBR-II spent fuel. And the mass of added waste is so small that it falls within the noise of uncertainty associated with this spent fuel treatment process. No new waste streams need to be characterized or handled.

Cost Estimate

No transportation costs are included in this proposal. These estimates assume that ANL will not be responsible for delivering the sources to the treatment site. It is very important to emphasize that no facility modifications are needed for this project. It has been verified that the existing hot cell windows are adequate for neutron shielding considering even a 400 Ci PuBe source.

Development Tasks and Costs

Criticality analyses for HFDA and ER	$15K
Modifications to the FMF molten salt furnace	$50K
Test oxide reduction with $^{239}PuO_2$ in molten salt furnace	$300K
Test electrorefining process with ^{239}Pu	$300K
Test oxide reduction with ^{238}Pu oxide sources in HFEF	$400K
Test electrorefining with ^{238}Pu oxide sources in HFEF	$400K
Issue process development test report	$20K
Total	**$1.48M**

It is assumed that approximately 60 sources will then be treated using this process. If all sources are delivered to ANL-West in a timely manner, it is anticipated that treatment could be complete within 2 years. That assumes that approximately 1 source is treated every 2 weeks.

Treatment

Operational support (2 years)	$500K/year
Total	**$1.0M**

Total for Project	**$2.48M**

Appendix N

Options for Disposal of Sealed Neutron Sources at SRTC

The Department of Energy is seeking options for disposition of large sealed neutron sources. Disposal routes elsewhere appear viable up to 54 Curies/source, but a small number of larger sources have no apparent disposition path. The most recent neutron source inventory shows 26 sources exceeding 60 Curies/source. Of this number, 21 are ^{238}Pu-Be, 2 are ^{238}Pu-Li, and 3 are ^{241}Am-Li. Most of the Curie count is in the ^{238}Pu-Be sources; most of this (~4650 Ci) is at Bettis in 12 sources. The Savannah River Technology Center (SRTC) was asked to study the possibility of processing these larger sources in SRTC facilities.

The SRTC has two separate facilities initially thought to offer a potential for processing the high-neutron sources: (1) the Californium Processing Facility (CPF); and (2) the High Level Cells (HLC). Both facilities are located within SRTC's 773-A building at the Savannah River Site. For reasons discussed below, the CPF does not appear to be suited to this mission, but with some minor modification, the HLC could be a viable option.

Two processing options were judged to have merit: (1) dissolution followed by discard of the actinides to high level waste, and incorporation of the Be into a binder for disposal as solid TRU waste; and (2) physical separation and repackaging for disposition to WIPP as lower-Curie sources. Both options are discussed below.

Facility Capabilities

Californium Processing Facility

The SRTC Californium Processing Facility (CPF) was built in the early 70's to process Cf sources into implantable needles for medical uses, and operated until that mission was terminated in the late 70's. It has five cells with windows 36 inches thick, filled with water to shield high neutron radiation. This facility is idle and was thought to be of possible utility once again for the disposal of large neutron sources.

The size of the larger sources being considered for disposal today exceeds the neutron level allowed by the present SRTC risk envelope, but an initial judgment was that adding an additional layer of protection against release should allow use of the facility for processing these sources. To confirm that judgment, a risk-based safety assessment was requested. That assessment states that the facility would not survive a design-basis earthquake. The facility is constructed of concrete blocks, without adequate internal reinforcing to withstand the earthquake. A postulated consequence is that it would collapse to release its contents to the environment. Therefore, it represents a risk that is unacceptable for meeting today's standards.

Although no engineering estimate has been prepared which would indicate the project cost required to strengthen the facility for earthquake survival, the likely capital requirements are thought to be far in excess of what could be justified for this or any other likely future mission for the facility. An order of magnitude cost estimate was $3 million for preparing the idled CPF,

and $500K in annual operating costs, expected to last for about four years. So this option was abandoned.

High-Level Cells

The High-Level Cells (HLC) in E-wing of SRTC were also considered for their potential to process these sources. The E-Wing facility was built in the 50's to support the processing of reactor targets and fuel. The cells were constructed of reinforced concrete ~3 feet thick. The cells are actively in use, are part of the current SRTC safety basis, and have been determined to be able to withstand the design-basis earthquake.

The cells are now used primarily to support High Level Waste (HLW) processing including process development and sample analyses. The Hanford River Protection Project is utilizing several of the cells through 2006 for their HLW process development. The remaining cells are used for Defense Waste Processing Facility (DWPF) support and the salt disposition process development.

Calculations showed that the 25-Curie sources in SRTC would result in 25 millirem/hour neutron dose at the cell window (unacceptable by today's standards). Although these shielded cells provide excellent shielding of gamma radiation, their oil-filled, leaded-glass windows will not effectively shield strong neutron sources. However, the SRTC-HLC organization has developed a new quick-change window system and is in the process of installing this design over the next few years. This development opens the possibility of changing the shielding to accommodate high-neutron sources.

The original HLC window design necessitated a downtime of several weeks or months to replace a window. The cell windows of the new design can be replaced in only 1-2 days. Conceptually, a new polymer composite window with shielding similar to that in the CPF could be designed and installed for neutron shielding. The radiation limit would be expected to be equivalent to that of the CPF, or ~400 curies. This should accommodate the largest sources, the ^{238}Pu-Be sources from Bettis. With this quick-change design feature of the window, source recovery could be campaigned when cell time is available, followed by a quick changeover back to the gamma-shield window as needed. This would offer load-leveling of resources and allow HLC processing of sources for incremental costs.

Source Processing Options Considered

Description of Sources

The source dimensions typically range from 1.5 to 3.5 inches long and 1 to 1.5 inches in diameter, which is not expected to be physically limiting. Larger sources can be handled on a case by case basis. The physical limits of the cell will determine the acceptable source geometry. Sources longer than 4.5 feet would necessitate special shipping containers and handling equipment.

The sources are doubly encapsulated, normally in stainless steel. The source is a pressed compact of PuO_2 or AmO_2 powder intimately mixed with powdered beryllium metal or lithium hydroxide, metal, or hydride.

The highest neutron dose will be generated by the Pu-Be sources. The 21 sources fall into three groupings: ~60 Ci, ~110 Ci, and ~400 Ci. With a specific activity of about 17.1 Ci/g, a 60-Ci source would contain about 3.4 grams of Pu-238. A source 3.5" long X 1.5" diameter has a volume of 101 cm^3, and assuming an 80% packing fraction, would contain about 80g of Be or Li. The neutron emission from ^{238}Pu-Be is $2.4X10^6$ n/s-Ci, or $1.4X10^8$ n/s for a 60-Ci source. The radiation level of the source at 5 cm is estimated as 1.3 to 1.7 R/Ci, or about 90R for a 60-Ci source of ^{238}Pu-Be.

The average number of neutrons produced by alpha particles from Pu-238 or Am-241 striking Li is only about 3% of that produced from Be. So the radiation level of a 60-Ci ^{238}Pu-Li source at 5 cm would be about 3% of that from the ^{238}Pu-Be source, or about 2.7R.

The specific activity of Am-241 is about 3.43 Ci/g, or about one-fifth that of Pu-238. So the neutron emission from the Am-Li sources will be $8.4 X 10^5$, or less than 1% of that from a Pu-Be source of the same Curie rating.

Pu-238 has no appreciable gamma, but Am-241 has one 60 kev gamma per alpha. For a 60 Ci ^{241}Am-Li source at 5 cm, the neutron dose rate is approximately 2 rem/hr and the gamma dose rate is approximately 300 rem/hr, unsealed and with no self-shielding.[*] Although the Pu-Be sources require the greatest neutron shielding, the Am-Li sources will require both neutron and gamma shielding.

Disposition alternatives

Several alternatives were considered initially as possibilities for disposal of the large sealed sources. Eventually the possibilities were narrowed down to only two options that were considered viable—chemical processing and physical repackaging. Each option required approvals from the perspectives of risk assessment and waste disposal suitability. A summary flow sheet is shown on the next page.

Chemical Processing: Beryllium is an amphoteric element and dissolves in NaOH solution, while PuO_2 and AmO_2 are insoluble in basic solutions. The planned processing would involve cutting the capsule open, dissolving the Be in NaOH, and filtering out the PuO_2 or AmO_2. The radioactive component could be packaged and stored as the oxide, or dissolved and sent to high level waste, or purified and returned to a stockpile.

The solubility of $Be(OH)_2$ is greater than 1M in 3M NaOH, so there would be about 1 L of solution per 9g Be, or about 9 L solution for a 60-Ci source. Assuming 99% recovery of the Pu, there will still be of the order of 10^{12} d/m ^{238}Pu in the solution, or ca 10^8 d/m-mL. The NaOH-$Be(OH)_2$ solution could be mixed with an appropriate binder and transported to WIPP as TRU waste. It would not be acceptable for High Level Waste, which has a 28 ppm upper limit for Be. The Be would eventually end up in saltstone, which limits the Be because of long-term leaching into the groundwater.

[*] "Dose Rates for Am-Li Neutron Point Source for NSTS," Memorandum, L.C. Sanchez to C.A. Ottinger, Sandia National Laboratories, February 27, 2002.

Processing of Pu-Li or Am-Li sources would rely on the fact that Li, LiOH, and LiH will dissolve in water, whereas the PuO_2 and AmO_2 would not. Lithium and LiH dissolve violently in pure water, evolving H_2. This can be controlled by dissolving in a mixture of mostly alcohol with a small amount of water. Dissolution conditions would need to be confirmed before handling these sources, but with proper safety precautions that should be acceptable.

Physical Repackaging: In this option, one would unpack the source, cut it open, and divide it into small sources that would be repackaged as in the original source package — doubly encapsulated, welded, leak-tested, etc. Shipping would require the TRUPACT II containers. A disadvantage of this approach is that it wold lead to dusting of the cell interior with high-neutron source dust.

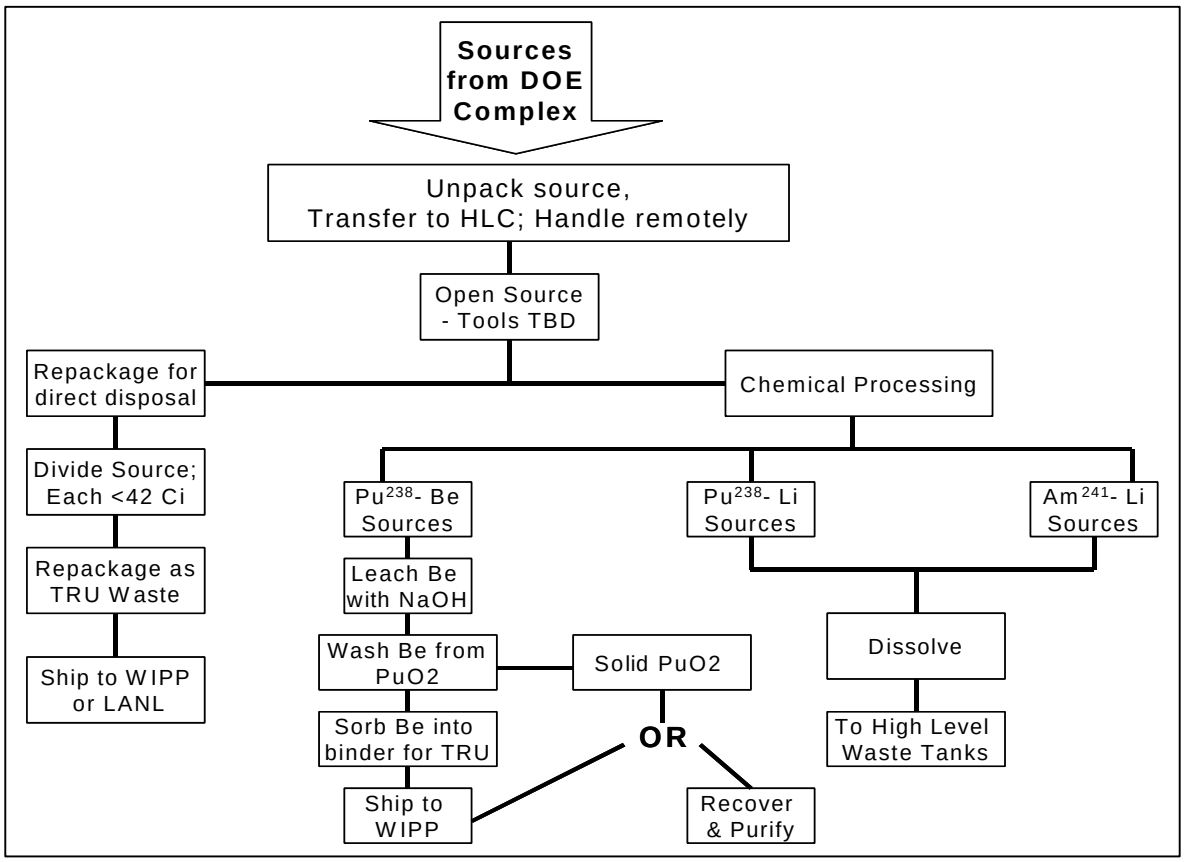


Figure 2. Source Disposition Options at SRTC

Cost and Timing

Costs

The cost to ready the one E-Wing cell for processing by either option and satisfy safety documentation was estimated as roughly $500K ($150K for safety documentation updates, $100K for equipment to cut sources, press compacts, weld small sources, etc., and $250K for new window fabrication and installation). Operation of the facility would require one technician and technical support, for a cost of about $250K per year (could be part-time if the program is not continuous). Shipping costs are not included in this estimate. These numbers are ballpark

estimates, based on experience—a detailed engineering study would be necessary to establish a firm cost estimate.

Timing
The earliest available time for a source recovery campaign in the HLC schedule is late 2003 – early 2004. The SRTC E-Wing cells are fully scheduled through late 2003, but after that time some availability is expected. The cells are an integral part of the SRTC support to DWPF (Waste glass processing) sample analysis, and will need to continue this support past 2020.

With a disposal path assured for the smaller sources, there are 26 large sources identified for disposal. On the premise that no more than one or two sources could be present in the facility at any time, the timing for disposition of all the sources will be determined more by shipping schedules and cell schedules than by actual processing time. With favorable shipping schedules, it is estimated that the entire program would require at least two years. With normal shipping, the entire campaign would probably take twice as long.

NEPA Coverage: Because SRS has processed Pu-238 as a primary mission and has sent it to the waste tanks before, the proposed mission for processing large sealed sources would not be expected to require any NEPA action. That expectation would need to be validated before a commitment can be made.

SRTC Processing Option

The processing steps in Figure 2 are as follows:

A. Receive sources from Complex – Limited storage capacity at SRS
B. Unpack sources and transfer to HLC – some remote handling may be required
C. Open the source – tools to be developed, but hacksaw and vise have been employed
D. Direct disposal
    1. Divide source into parts, each <42 curies
    2. Repackage for shipment to WIPP or LANL for disposal
E. Separation by dissolution, with possible recovery of the PuO_2

    1. Cut open the source
    2. Leach Be with caustic
    3. Wash the Be from the PuO_2
    4. Absorb Be into a binder and transport it to WIPP as TRU waste
    5. Dissolve the Pu in nitric/hydrofluoric acid
    6. Purify the Pu with ion exchange column
    7. Precipitate the Pu with oxalate
    8. Calcine to PuO_2
    9. Package for recycle
F. Waste Tank Disposal
    1. Cut open the source
    2. Dissolve the Pu and Be in nitric/hydrofluoric acid
    3. Neutralize to pH 5.5 and send to waste tanks

        (Be will end up in saltstone and Pu will end up in glass)

If there are any other sources that are too big for direct disposal (i.e. Am-Li or Pu-Li sources) slight variations on this flow sheet are required, but they would still be feasible.